JOURNAL OF AGRICULTURAL RESEARCH

VOL. 50 WASHINGTON, D. C., MARCH 1, 1935 No. 5

EFFECT OF CROWN RUST INFECTION ON YIELD AND WATER REQUIREMENT OF OATS[1]

By H. C. MURPHY[2]

Assistant pathologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

Crown rust (*Puccinia coronata avenae* Eriks.), the most generally prevalent rust of oats (*Avena sativa* L.), is virtually coextensive with oat culture. Estimated annual losses caused by the rust in the United States from 1918 to 1930, inclusive, averaged more than 13,700,000 bushels. Immer and Stevenson (*3*)[3] and Immer and Ausemus (*2*) have shown that severity of crown rust infection is negatively correlated with yield, plumpness, date of heading, and height of oats. Weaver (*11*) stated that the water requirement

$$\left(\frac{\text{weight of total water transpired}}{\text{total dry weight}}\right)$$

of seedling oat plants bearing an infection of 0.5 percent of stem rust (*P. graminis avenae* Eriks. and Henn.) on the first leaf was 37 percent greater than that of nonrusted plants. His observations were limited to a period of 7 days and included only 8 diseased and 9 control plants. He used crown rust in an earlier experiment extending over a period of 153 hours and found the transpiration of the seedling plants with crown rust on the first leaf to be 94 percent greater than that of similar nonrusted plants.

The effect of rust infection on the water requirement of other cereals has been reported by only a few investigators. Weiss (*12*) studied the effect of stem rust and leaf rust infection on the yield and water requirement of Marquis wheat. He found that rusted plants had a higher water requirement than nonrusted ones, although the differences were significant only in the case of stem rust infection. Infection with either rust caused a significant reduction in yield of tops and of grain, the yield of the latter being most affected. Weaver (*11*) studied rust-infected wheat, rye, barley, and corn, in addition to oats, and found that the transpiration rate was consistently higher in the rusted plants. Johnston and Miller (*4*) have published a preliminary report of their studies on the effect of leaf rust infection on water economy and growth of wheat. They found that the water requirement of susceptible varieties increased with increasing length of association of host and parasite, while the yield of all plant parts was materially reduced.

[1] Received for publication Oct. 10, 1934; issued May 1935. Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, and the botany and plant pathology section of the Iowa Agricultural Experiment Station.

[2] The writer gratefully acknowledges his indebtedness to Dr. H. B. Humphrey, of the Division of Cereal Crops and Diseases, at whose suggestion the research was undertaken, for assistance in the preparation of this manuscript, and to Dr. W. E. Loomis, of the botany and plant pathology department of the Iowa State College, for valuable suggestions and criticisms during the course of the experiments.

[3] Reference is made by number (italic) to Literature Cited, p. 410.

The experiments reported in this paper were planned as a more extensive investigation of the relation of crown rust infection to yield and water requirement of resistant and susceptible oat varieties. Data are presented that give information concerning (1) the relation of the total duration of crown rust infection to reduction in yield of a susceptible variety growing under field conditions, (2) the relation of the total duration of infection to yield and water requirement of a susceptible pure line and a resistant one growing under greenhouse conditions, and (3) the interrelations of soil moisture and time of initial infection with yield and water requirement of 2 susceptible lines and 1 resistant pure line under greenhouse conditions. A preliminary report of this work has been published by the writer (*8*).

EFFECT OF CROWN RUST INFECTION ON YIELD OF FIELD-GROWN OATS

MATERIAL AND METHODS

An investigation was conducted in the summer of 1928 to determine the relation between the total duration of crown rust infection and the subsequent reduction in yield of a susceptible oat variety growing under field conditions. A pure-line selection of Iomine oats (C. I.[4] no. 2827) was sown uniformly on April 12 in 30 consecutive plots of 10-rod rows (one two-hundred-and-sixty-fourth of an acre) each at Ames, Iowa. The plots were spaced 3 feet apart, while the rod rows within the plot were 1 foot apart. Soon after the seed was sown, a heavy rain partly eroded plots 7 and 21 and they were later omitted from the experiment. The plants in 15 of the 28 plots were dusted on certain dates with sulphur at the rate of 15 pounds per acre, while those in 8 of the remaining 13 plots were artificially inoculated with crown rust at definite intervals. Urediospores were obtained in abundance from heavily rusted greenhouse plants and dusted on the moistened plants soon after sundown. The number and arrangement of the plots in relation to the treatment given are shown in table 1.

RESULTS

The year 1928 was very nearly ideal for a study of the effect of crown rust infection on yield of field-grown oats at Ames, because there was an almost complete absence of natural dissemination of either crown rust or stem rust. There was, however, a considerable spread of crown rust from artificially inoculated plants to nearby plots. Stem rust was almost entirely absent, not more than a trace being observed in any of the oat plots.

The kinds and dates of treatment, percentage of crown rust infection on July 5, bushel weight, and acre yield for each of the 28 plots of Iomine oats grown in 1928 are given in table 1. Dusting with sulphur did not entirely prevent the incidence of crown rust, although it was remarkably effective, considering the lateness and the small number of applications. The spread of crown rust from the plots first artificially inoculated was evident. The percentage of infection in each of the plots was recorded on July 5, when crown rust apparently had attained its maximum intensity in all of the plots, although it had appeared in the artificially inoculated ones in great abundance 7 or 8 days after the first inoculation. The sulphur-dusted plants then averaged soft- to hard-dough stage of development.

[4] C. I. refers to accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

TABLE 1.—*Effect of crown rust infection on bushel weight and acre yield of 28 plots of Iomine oats grown at Ames, Iowa, in 1928*

Plot no.	Treatment	Dates of treatment	Percentage of infection on July 5[1]	Weight per bushel	Yield per acre	Difference between rusted plot and average of 2 adjacent plots	
						Weight per bushel	Yield per acre
		June		*Pounds*	*Bushels*	*Pounds*	*Bushels*
1	Dusted with sulphur	24, 27, 29	10	28.0	65.0		
2	Artificially inoculated[2]	9, 16, 22, 29	100	20.6	33.2	−6.05	−34.05
3	Dusted with sulphur	24, 27, 29	15	25.3	69.5		
4	Artificially inoculated[2]	9, 16, 22, 29	100	19.3	23.4	−5.35	−40.05
5	Dusted with sulphur	24, 27, 29	10	24.0	57.4		
6	Artificially inoculated[2]	16, 22, 29	100	21.6	44.6	−3.40	−24.50
8	Dusted with sulphur	24, 27, 29	10	26.0	80.8		
9	Artificially inoculated[2]	16, 22, 29	100	23.0	57.2	−4.00	−23.75
10	Dusted with sulphur	24, 27, 29	5	28.0	81.1		
11	Artificially inoculated[2]	22, 29	100	23.6	54.4	−3.40	−21.60
12	Dusted with sulphur	24, 27, 29	5	26.0	70.9		
13	Artificially inoculated[2]	22, 29	100	22.6	49.3	−3.20	−20.80
14	Dusted with sulphur	24, 27, 29	3	25.6	51.3		
15	Artificially inoculated[2]	29	100	25.0	31.1	−2.80	−29.40
16	Dusted with sulphur	24, 29	[3] t+	26.0	69.7		
17	Artificially inoculated[2]	29	100	25.0	45.7	−2.80	−27.80
18	Dusted with sulphur	24, 29	t+	29.6	77.3		
19	None		45	26.6	60.4	−2.50	−15.55
20	Dusted with sulphur	24, 29	t	28.6	74.6		
22	do	24, 29	t	26.6	66.3		
23	None		30	25.0	42.9	−2.10	−16.90
24	Dusted with sulphur	24, 29	t	27.6	53.3		
25	None		20	24.6	38.7	−2.50	−10.05
26	Dusted with sulphur	24, 29	t−	26.6	44.2		
27	None		15	25.0	35.4	−2.10	−10.60
28	Dusted with sulphur	24, 29	t−	27.6	47.8		
29	None		10	24.0	45.0	−2.60	−7.10
30	Dusted with sulphur	24, 29	t−	25.6	56.4		

[1] The percentage severity of rust infection was determined by comparison with the scale for estimating rust percentages adopted by the Division of Cereal Crops and Diseases.
[2] None of the artificially inoculated plots was sulphur-dusted.
[3] Trace of infection is indicated by t.

The plants first inoculated with crown rust on June 9 were in full head about 5 days later than those in the adjoining sulphur-dusted plots. These same rusted plots appeared to ripen about 4 days earlier than the adjoining sulphur-dusted ones. The ripening was premature, however, and was doubtless caused by the increased susceptibility of the heavily rusted plants to the very hot, dry weather. The other artificially inoculated plots were affected similarly but to a less degree.

The differences in both acre yield and weight per bushel between the plots heavily infected with crown rust and the adjoining sulphur-dusted plots are apparently highly significant in every case. The data presented in table 1 may be summarized by calculating the average weight per bushel and the yield of the replicated treatments. Because of the presence of a considerable degree of soil heterogeneity, it seems preferable to compare the replicated rusted plots with the immediately adjoining sulphur-dusted ones only. The average weight per bushel and yield of the various replications and the percentage weight and yield in comparison with those of the immediately adjoining sulphur-dusted plots are presented in table 2.

TABLE 2.—*Effect of crown rust infection on bushel weight and acre yield of certain plots of Iomine oats grown at Ames, Iowa, in 1928*

[Values are averages of plots treated]

Plot no.	Treatment	Dates of treatment	Infection on July 5	Weight per bushel		Yield per acre	
		June	*Percent*	*Pounds*	*Percent*	*Bushels*	*Percent*
1, 3, 5	Dusted with sulphur	24, 27, 29	11.7	25.77	100.0	63.97	100.0
2, 4	Artificially inoculated	9, 16, 22, 29	100.0	19.95	77.4	28.30	44.2
5, 8, 10	Dusted with sulphur	24, 27, 29	8.3	26.00	100.0	73.10	100.0
6, 9	Artificially inoculated	16, 22, 29	100.0	22.30	85.8	50.90	69.6
10, 12, 14	Dusted with sulphur	24, 27, 29	4.3	26.53	100.0	67.77	100.0
11, 13	Artificially inoculated	22, 29	100.0	23.10	87.1	47.35	69.9
14, 16, 18	Dusted with sulphur	[1] 24, 29	1.2	27.07	100.0	66.10	100.0
15, 17	Artificially inoculated	29	100.0	24.00	88.7	38.40	58.1
18, 20, 22, 24, 26, 28, 30	Dusted with sulphur	24, 29	.2	27.46	100.0	59.99	100.0
19, 23, 25, 27, 29	None		24.0	25.04	91.2	44.48	74.1

[1] Plot 14 was dusted with sulphur June 24, 27, and 29.

The greatest decrease in bushel weight and in yield per acre was observed in those plots first artificially inoculated on June 9. These plots yielded 44.2 percent as much as the adjoining sulphur-dusted ones, and the bushel weight of the grain from the artificially inoculated plots was only 77.4 percent as much as that of the grain from the sulphur-dusted check plots. The decrease doubtless would have been even greater had the sulphur dusting entirely prevented the appearance of rust in the check plots. Those plots in which the initial inoculation was made on June 16, a week later, showed a much smaller reduction in bushel weight and yield. There was no significant difference in reduction in yield between the replications initially inoculated on June 16 and June 22, respectively. There was, however, an apparently significant difference in the bushel weights of the two treatments. The reduction in yield of the plots inoculated June 29 was greater than that of those inoculated June 16 and 22, although the reduction in bushel weight was smaller. The fact that the former were dusted with double the quantity of spores used for the others inoculated on the same date may account in part for the unexpectedly greater reduction in yield, although on July 5 there was no apparent difference in the degree of infection in any of the artificially inoculated plots. The secondary infection in plots 2, 4, 6, and 9 was apparently equal to that resulting from the extra inoculum used on plots 15 and 17. There was sufficient spread of rust from the artificially inoculated plots to produce an average of 24 percent infection in the five untreated plots. This apparently reduced the yield approximately one-fourth, while the percentage weight of the bushel was 8.8 less.

It is evident that there is a definite relation between duration of rust infection and bushel-weight reduction. Apparently the earlier the incidence of infection the greater will be the reduction in weight. This relationship, no doubt, would have been even more evident had the sulphur applications been made early and frequently enough to prevent the appearance of any crown rust in the check plots. No such exact indication of relationship appeared between the time of initial infection and yield, although, with the exception of replicated plots 15 and 17, there appears to be a similar relationship. The

reduction in yield in these two plots is greater than would be expected on the basis of the bushel weight and from the results obtained later from greenhouse experiments.

There was no indication that sulphur in itself significantly affected the yield. In an experiment conducted on the agronomy farm by the Soils Department of the Iowa State College, the application of sulphur to the soil did not result in any increase in the yield of oats.

EFFECT OF CROWN RUST INFECTION ON WATER REQUIREMENT AND YIELD OF GREENHOUSE-GROWN OATS

The data obtained from the field experiment conducted in 1928 and from numerous other field observations have shown that oats infected with crown rust yield less than rust-free oats and that the subsequent reduction in bushel weight and yield is positively correlated with the earliness and severity of infection. The latter is measured both by degree and type of infection. A highly resistant or nearly immune plant may be as extensively infected as a completely susceptible plant, although this will not ordinarily be the case under field conditions. It is important, however, to know what relation, if any, there is between type of infection and reduction in yield. Since soil moisture and crown rust infection, alone or together, are often limiting factors in successful oat production, it seemed desirable to determine the interrelations of soil moisture, water requirement, rust infection, and yield. To facilitate the control and measurement of these factors, 2 sets of experiments were conducted, 1 in 1930 and 1 in 1933. Substantially the same methods were employed in both cases, except that in 1933 some plants were grown with and some without adequate soil moisture.

EXPERIMENTS IN 1930

Material and Methods

In the experiments conducted in the greenhouse in 1930 pure-line selections of Victoria (C. I. 2401) and Markton (C. I. 2053) were used. Victoria is immune or nearly immune from or highly resistant to each of the 33 physiologic forms of *Puccinia coronata avenae* studied by the writer (7), while Markton is moderately or completely susceptible. One hundred and five 1-gallon glazed jars, each containing 4 kg of a 3-to-1 mixture of greenhouse compost and sand of uniform fertility and moisture, were used for this experiment. In order to add water to the soil directly and conveniently, an inverted 2½-inch clay flowerpot resting on a glass plate 3 inches square was placed 2 inches from the bottom of each jar and the soil was then added. A glass tube extended from within the clay pot to 3 inches above the top of the jar. Six primary grains of Victoria oats were sown in each of 50 jars on January 22; similarly, 50 jars were sown with Markton, leaving 5 jars without seed. One kilogram of clean white sand was placed on top of the soil in each jar to reduce surface evaporation. The moisture content of the soil and sand when placed in the jars was 13.95 and 3.25 percent, respectively. After the seed was sown, the soil moisture in each jar was raised to 60 percent of its water-holding capacity, or 24 percent of the dry weight, and held within a range of 55 to 65 percent of saturation by adding water at necessary intervals. The evaporation through the sand cover was estimated from the loss in weight

of the 5 jars without seed, which were kept at the optimum soil moisture. The temperature was maintained within the range 65° to 85° F.

After emergence, the number of plants was reduced to 4 per jar. When the plants were in the seedling (four-leaf) stage, 10 jars of each set were dusted with urediospores of physiologic form 1 of crown rust. A like number of each set were dusted in the early boot, early anthesis, and early dough stages, respectively, and each of the four lots was reinoculated every 2 weeks. Inoculation was accomplished by placing the plants in a large glass incubation chamber, spraying them with tap water, and dusting them with rust spores. They were allowed to remain in the chamber for 24 hours before removal to the greenhouse bench.

The dry weight of the grain, straw,[5] and roots was obtained for all the plants used in the experiments conducted in 1930 and 1933. In each experiment, the plants when mature were harvested simultaneously. Of those that developed no panicles because of rust, some, though dying, were still partly green when harvested. The roots were harvested by washing away the soil with a light stream of water. The loss of parts of the smaller roots was probably proportional for each series and insufficient to affect the significance of the differences in yield of roots between different series. The grain was carefully hand-threshed.

Results

The susceptible Markton plants initially inoculated in the seedling stage failed to head and produced 35.2 and 4.4 percent as much straw and roots, respectively, as the rust-free plants of the check (tables 3 and 4). The water requirement[6] of these plants was almost four times that of the nonrusted plants. Although the plants were first inoculated in the four-leaf stage, they were not entirely dead when harvested. The 2-week interval between inoculations permitted a certain degree of recuperation, especially when the plants were young. Nearly as striking was the reduction in yield of the plants initially inoculated in the early boot stage. The development of the panicles was almost completely arrested when the resulting infection appeared, and the few that did emerge were barren. At the time of anthesis the grain and roots were still susceptible to considerable retardation, while the rest of the plant was apparently much less affected when inoculated at this time. The water requirement of the plants initially inoculated at this stage of development was 42.3 percent greater than that of rust-free plants. There was no significant effect on either yield or water requirement of those plants initially inoculated in the dough stage.

[5] Straw includes everything except grain and roots.

[6] The term "water requirement" as used herein refers to the ratio of the weight of water absorbed by a plant during its entire growth period to the weight of dry matter produced, including that of the roots.

TABLE 3.—*Mean yield and water requirement, per jar of four plants, of pure-line selections of Markton and Victoria oats grown in the greenhouse and infected with physiologic form 1 of Puccinia coronata avenae at different stages of development, in 1930*

MARKTON (SUSCEPTIBLE)

Stage at initial infection	Average weight				Average water used	Average water requirement
	Grain	Straw	Roots	Total		
	Grams	*Grams*	*Grams*	*Grams*	*Kilograms*	
Seedling	0.0	24.7±0.3	0.7±0.1	25.4±0.3	21.2	833.9±12.5
Boot	.0	35.1± .2	2.0± .1	37.1± .2	22.6	610.2± 2.7
Anthesis	14.1±0.5	61.8± .5	4.7± .6	80.6± .6	24.5	303.6± 2.2
Dough	25.1± .3	71.0± .5	14.8± .3	110.9± .9	24.6	222.1± 2.5
Check	25.8± .1	70.2± .3	16.0± .2	112.0± .3	23.9	213.4± 3.1

VICTORIA (RESISTANT)

Seedling	12.6±0.2	54.5±0.5	9.2±0.2	76.3±0.7	23.9	313.0±2.2
Boot	16.6± .4	57.9± .4	11.3± .1	85.8± .7	23.8	277.3±2.2
Anthesis	19.6± .4	61.3± .5	16.3± .5	97.2±1.1	23.9	245.6±2.4
Dough	23.6± .2	65.6± .4	20.1± .5	109.3± .9	24.2	221.4±1.8
Check	24.0± .2	63.9± .3	20.3± .4	108.2± .5	24.2	223.7±1.1

TABLE 4.—*Mean yield and water requirement of Markton and Victoria oats infected with Puccinia coronata avenae at different stages of development, in 1930*

MARKTON (SUSCEPTIBLE)

Stage at initial infection	Yield [1] of—				Water requirement [1]
	Grain	Straw	Roots	Total	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Seedling	0.0	35.2	4.4	22.7	390.8
Boot	.0	50.0	12.5	33.1	285.9
Anthesis	54.7	88.0	29.4	72.0	142.3
Dough	97.3	101.1	92.5	99.0	104.1
Check	100.0	100.0	100.0	100.0	100.0

VICTORIA (RESISTANT)

Seedling	52.5	85.3	45.3	70.5	139.9
Boot	69.2	90.6	55.7	79.3	124.0
Anthesis	81.7	95.9	80.3	89.8	109.8
Dough	98.3	102.7	99.0	101.0	99.0
Check	100.0	100.0	100.0	100.0	100.0

[1] Percentage of that of rust-free check.

As would be expected, the yield and water requirement of the resistant Victoria selection were not affected nearly so much by crown rust infection as were those of the susceptible Markton selection. Victoria plants initially infected in the seedling stage were affected to about the same degree as Markton plants initially infected during anthesis. The value and significance of the differences between the mean yields and water requirements of the different series for both selections are shown in table 5.[7]

[7] The value of t and its significance were calculated and determined by the method and tables given by Fisher (*1*) and Snedecor (*9*). The value of t represents the ratio of the mean difference to the standard deviation of the mean difference. As the value of t becomes larger the significance of the mean difference becomes greater. With 18 degrees of freedom, the least value of t that can be considered significant is 2.1 and the least value that can be considered highly significant is 2.9.

TABLE 5.—*Significance of differences in mean yield and water requirement of Markton and Victoria oats infected with Puccinia coronata avenae at different stages of development, in 1930*

[Values in boldface type are highly significant (indicating a level of significance beyond Fisher's 1-percent point, odds 99 to 1 or greater)]

Stages at initial infection	Mean difference and *t* value									
	Grain		Straw		Roots		Total weight		Water requirement	
	MD	*t*	MD	*t*	MD	*t*	MD	*t*	MD	*t*
MARKTON (SUSCEPTIBLE)										
Check seedling	25.8	**166.7**	45.5	**82.1**	15.3	**49.8**	86.6	**137.6**	620.5	**36.0**
Check boot	25.8	**166.7**	35.1	**78.5**	14.0	**44.6**	74.9	**139.0**	396.8	**72.6**
Check anthesis	11.7	**46.5**	8.4	**11.3**	11.3	**46.4**	31.4	**33.7**	90.2	**17.8**
Check dough	.7	1.7	−.8	.9	1.2	2.0	1.1	.9	8.7	1.6
Boot seedling	.0	.0	10.4	**20.0**	1.3	**11.9**	11.7	**21.5**	223.7	**13.1**
Anthesis boot	14.1	**70.7**	26.7	**37.0**	2.7	**22.5**	43.5	**69.4**	306.6	**67.0**
Dough anthesis	11.0	**33.1**	9.2	**8.4**	10.1	**25.5**	30.3	**21.1**	81.5	**18.7**
VICTORIA (RESISTANT)										
Check seedling	11.4	**28.5**	9.4	**11.0**	11.1	**17.3**	31.9	**29.4**	89.3	**27.9**
Check boot	7.4	**12.5**	6.0	**8.5**	9.0	**14.8**	22.4	**20.3**	53.6	**16.4**
Check anthesis	4.4	**7.5**	2.6	**3.4**	4.0	**4.8**	11.0	**7.2**	21.9	**6.3**
Check dough	.4	.9	−1.7	2.4	.2	.3	1.1	.8	2.3	.8
Boot seedling	4.0	**6.6**	3.4	**3.7**	2.1	**6.5**	9.5	**7.8**	35.7	**8.7**
Anthesis boot	3.0	**3.8**	3.4	**4.1**	5.0	**8.0**	11.4	**6.8**	31.7	**7.3**
Dough anthesis	4.0	**6.6**	4.3	**5.1**	3.8	**4.4**	12.1	**6.7**	24.2	**6.1**

Markton is completely susceptible to crown rust physiologic form 1, while Victoria is highly resistant. The uredia on Markton were large, with no necrosis and little or no chlorosis immediately surrounding them. In the case of Victoria the uredia were comparatively few, very small, and always surrounded by necrotic areas; also, there were numerous necrotic areas that failed to produce uredia. The percentage of actual infection on the two varieties was approximately equal throughout the investigation and was regularly 90 to 100 percent following each inoculation. The effect of the rust on yield and water requirement was much greater for Markton (figs. 1 and 2). Plants of both varieties initially inoculated in the seedling, early boot, and first anthesis stages of development showed a highly significant reduction in yield of all plant parts and a consequent increase in water requirement as compared with those of the rust-free plants. In each variety there were also highly significant differences between the effects of the rust on these different series. Infection resulting from inoculation made in the dough stage evidently was too late to affect significantly the yield and hence the water requirement of either variety.

In the greenhouse, where the soil moisture was held nearly constant and optimum, crown rust infection retarded both heading and ripening (fig. 3). Markton plants initially inoculated in the seedling and early boot stages failed to head at all, while in the remaining series all of the plants headed at the same time. Those plants initially inoculated in early anthesis matured about 4 days later than the rust-free plants. Victoria plants, inoculated in the seedling, early boot, early anthesis, and dough stage, were in full head on May 22, 17, 12, and 12, respectively. The dates of ripening were correspondingly affected.

The reduced yield of grain of Markton resulted from complete absence of kernels on those plants initially inoculated in the seedling and early boot stages and fewer and lighter kernels for those first inoculated in early anthesis (fig 4). Rust infection during anthesis caused much floral sterility and reduction in size of grains. The percentage of hulls also was definitely affected. The grain harvested from those plants first infected in this stage of development contained 31.4 percent of hulls, while that from the rust-free plants contained only 20.6 percent. Crown rust infection of Victoria, even when started in the seedling stage, seemed to cause little sterility. Most of the reduction in yield of grain was apparently due to smaller and lighter kernels (fig. 5). The effect of rust on the percentage of hulls

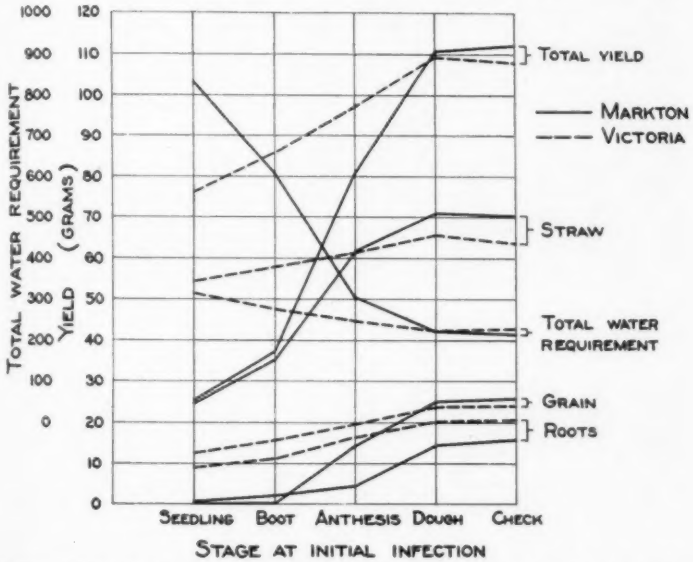

FIGURE 1.—Yield and water requirement of a susceptible selection of Markton oats and a resistant selection of Victoria oats initially infected with form 1 of crown rust in seedling, boot, anthesis, and dough stage in 1930.

in the grain harvested from the different series of Markton and Victoria is shown in table 6.

TABLE 6.—*Effect of rust on percentage of hulls in grain from Markton and Victoria oats, 1930*

Stage at initial infection	Markton	Victoria
	Percent	*Percent*
Seedling	(1)	29.2
Boot	(1)	27.9
Anthesis	31.4	26.1
Check	20.6	25.0

[1] No grain.

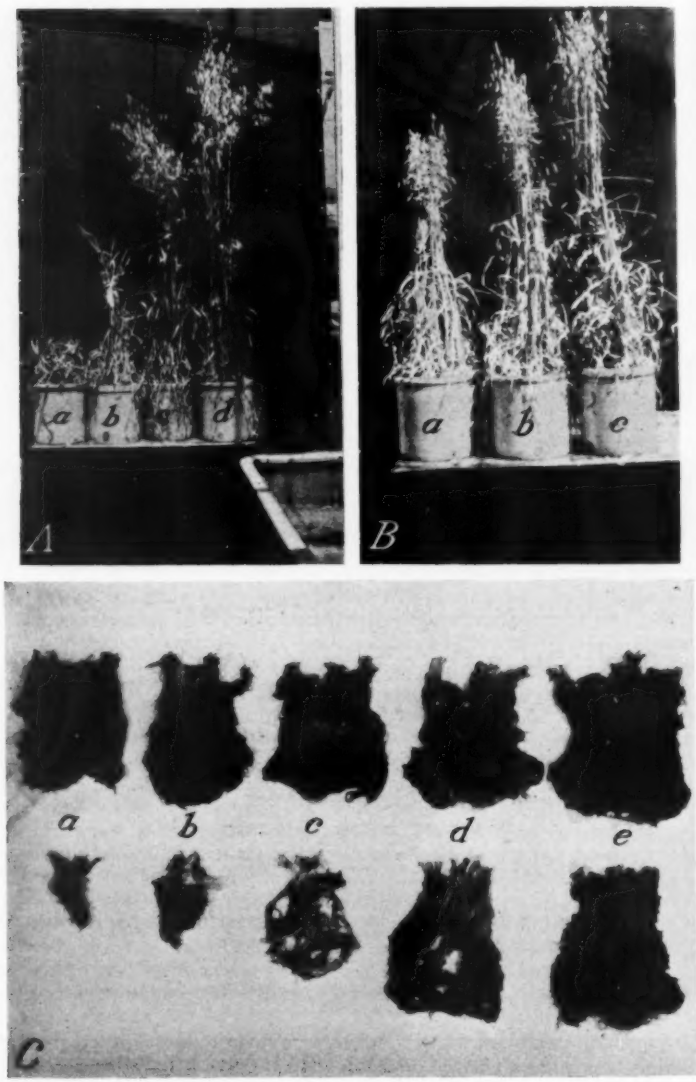

FIGURE 2.—Effect of crown rust infection on yield of a susceptible selection of Markton oats and a resistant selection of Victoria oats: *A*, Markton, initially infected in (*a*) seedling, (*b*) boot, and (*c*) anthesis stage; (*d*) check. *B*, Victoria, initially infected in (*a*) seedling, (*b*) boot, and (*c*) anthesis stage. *C*, Roots from Victoria (upper) and Markton (lower) initially infected in (*a*) seedling, (*b*) boot, (*c*) anthesis, and (*d*) dough stage; (*e*) check.

The average quantity of water used weekly by the Markton and Victoria plants in the different series is shown in figures 6 and 7. The data for plants inoculated first in the dough stage are not included because in neither variety did they differ significantly from the uninoculated plants. Although the water requirement of both varieties was greatly increased as a result of rust infection, the total water consumption of the infected plants initially inoculated in the seedling and boot stages was lower than that of the rust-free plants (table 3). The retardation of growth caused by the rust and the consequent reduction in yield resulted in a lower total water consumption but in a higher ratio of water to total dry weight. The direct effect of

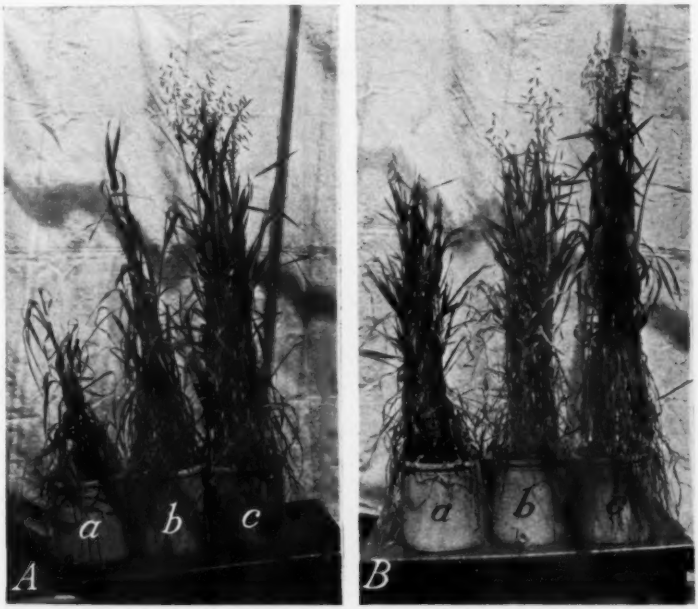

FIGURE 3.—Effect of crown rust infection on heading of (*A*) Markton oats and (*B*) Victoria oats, initially inoculated in (*a*) seedling, (*b*) boot, and (*c*) anthesis stage. Photographed May 10, 1930, at the time of the anthesis stage inoculation.

crown rust infection on transpiration is evident following the initial inoculation of the Markton plants infected first in the seedling, boot, and anthesis stages (fig. 6). Coincident with the appearance of uredia, the water loss from the initially inoculated plants in these series showed a significant increase over that from similar noninfected plants. This difference was evident until the infected tissues began to die, i. e., about 2 weeks after the appearance of uredia. A similar but less striking difference was evident in the water consumption of initially inoculated Victoria plants. Since the degree of infection on the two varieties was approximately equal, it appears that infection with many large uredia and no necrosis causes greater retardation of growth and destruction of tissue, as well as greater increase in transpiration, than does infection with a few small uredia and much necrosis.

EXPERIMENTS IN 1933

MATERIAL AND METHODS

An experiment somewhat similar to the one just described was conducted in 1933, except that 4-gallon instead of 1-gallon jars were used, and ground cork rather than sand was employed to prevent evaporation. Sixty-five jars, each containing 15 kg of greenhouse compost and sand in the ratio of 3 to 1, with an inverted 4-inch flowerpot as a water reservoir, were used. Primary grains of three pure lines of oats, selected from the varieties Markton (C. I. 2053), Victoria (C. I. 2401), a pure-line selection susceptible to form 7, and Bond (C. I. 2733), were planted, 20 grains per jar, with 20 jars for each pure line. After emergence the number of plants per jar was reduced to 15. Five

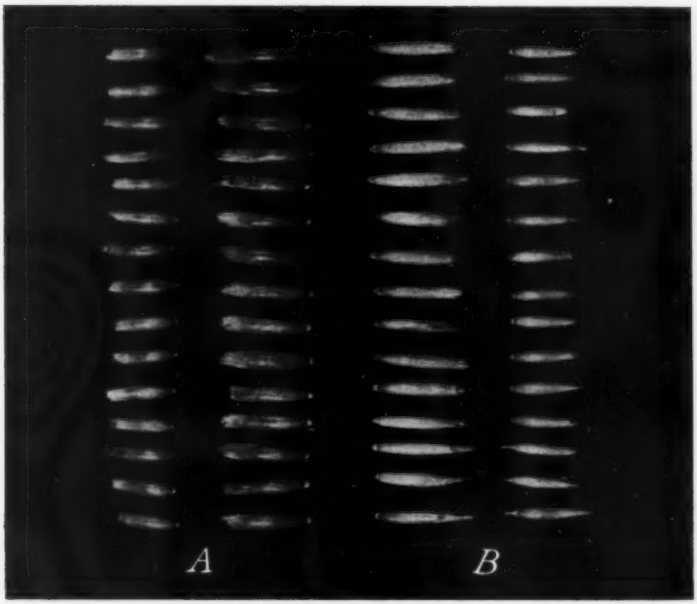

FIGURE 4.—Mechanically separated random samples of primary (larger) and secondary (smaller) grains from a susceptible selection of Markton oats: *A*, noninfected; *B*, initially infected in the anthesis stage with form 1 of crown rust in 1930.

jars were not planted. The moisture content of the soil when added to the jars was 11 percent of the dry weight. Immediately after planting, the moisture content of the soil of 12 jars of each pure line and of 3 of the jars without seed was brought up to 85 percent of its water-holding capacity, while that of the remaining 8 jars of each pure line and of the 2 jars without seed was raised to 50 percent of its water-holding capacity. The soil in these two sets was maintained at a moisture content of 80 to 90 percent and 45 to 55 percent of saturation, respectively.

Plantings were made on April 9, 11 weeks later than for the similar studies in 1930. This allowed for the longer days and higher temperatures that more nearly correspond to those of the field. No

attempt was made to maintain a constant temperature, and in June and July the temperature in the greenhouse was often 90° to 100° F. The degree of infection on the inoculated plants was held as near as

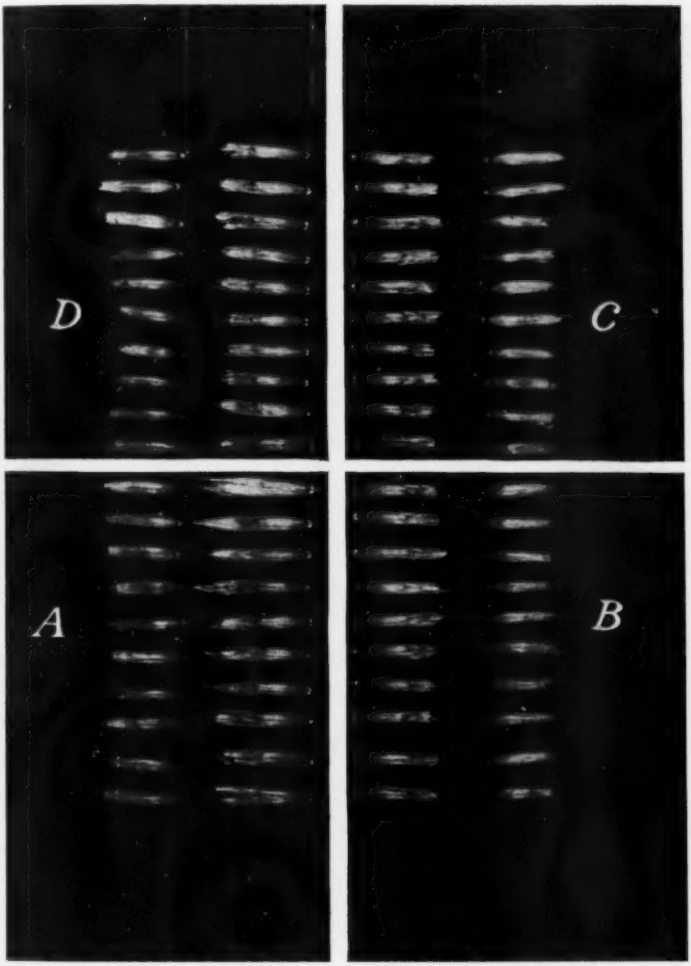

FIGURE 5.—Mechanically separated random samples of primary (larger) and secondary (smaller) grains from a resistant selection of Victoria oats: *A*, noninfected; *B–D*, initially infected in (*B*) seedling, (*C*) boot, and (*D*) anthesis stage with form 1 in 1930.

possible to 50 percent, and that on the susceptible selections always within the range of 40 to 70 percent.

The plants in 5 jars of each variety (3 with 85 percent and 2 with 50 percent soil moisture) were initially inoculated in the seedling stage with form 7 of crown rust and reinoculated every 2 weeks until maturity. Similarly, plants of each pure line in an equal number of jars

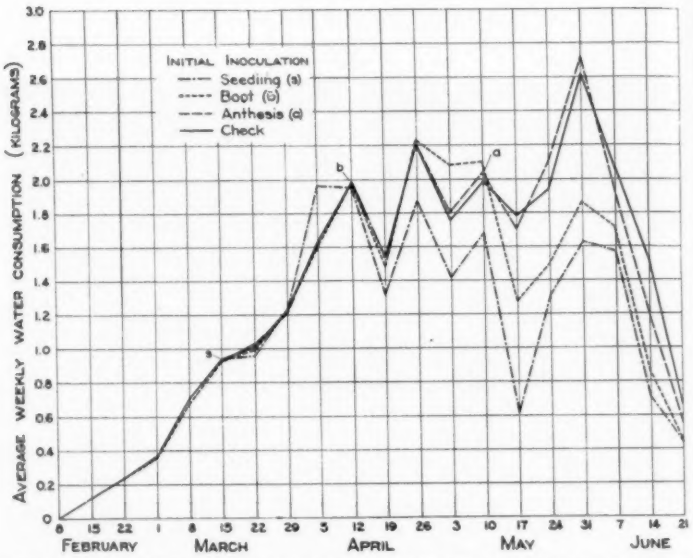

FIGURE 6.—Average weekly water consumption of a susceptible selection of Markton oats initially inoculated in seedling (*s*), boot (*b*), and anthesis (*a*) stage, in comparison with the noninfected check, in 1930.

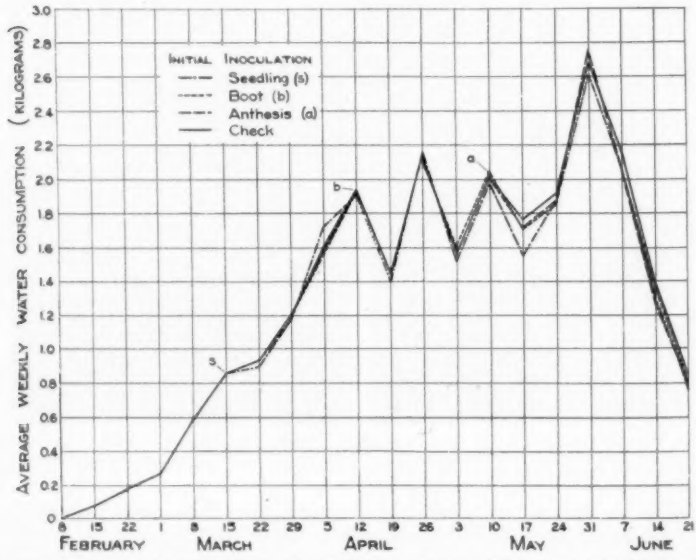

FIGURE 7.—Average weekly water consumption of a resistant selection of Victoria oats initially inoculated in the seedling (*s*), boot (*b*), and anthesis (*a*) stage in comparison with the noninfected check, in 1930.

were initially inoculated in the boot and early anthesis stages, while one set was retained as an uninoculated check. The plants were inoculated in the manner previously described, except that the urediospores were diluted with pure talcum powder before dusting. Initial inoculations in the dough stage were omitted in 1933 because infection initiated in this stage of development in 1930 did not affect significantly the yield or water requirement of either Markton or Victoria.

Results

The yield and water requirement of Markton, Victoria, and Bond, grown at 85- and 50-percent soil moisture and first inoculated with form 7 of crown rust in the seedling, boot, and anthesis stages, are shown in tables 7 and 8. The significance of the variation in yield due to experimental error or variation within classes, effect of rust infection initiated in different stages of the development of the host, effect of soil moisture, and the interaction or change in difference from stage to stage was determined by the method of analysis of variance described by Snedecor (*9*).[8] The values of the mean squares and their significance are shown in table 9.

TABLE 7.—*Mean yield and water requirement, per jar of 15 plants, of pure-line selections of Markton, Victoria, and Bond oats grown in the greenhouse and infected with physiologic form 7 of Puccinia coronata avenae at different stages of development, in 1933*

MARKTON (SUSCEPTIBLE)

Stage at initial infection	Soil moisture (percentage of saturation)	Average weight				Average water used	Average water requirement
		Grain	Straw	Roots	Total		
		Grams	*Grams*	*Grams*	*Grams*	*Kilograms*	
Seedling	85	0.5	30.8	3.1	34.4	18.1	527
	50	.5	27.7	2.7	30.8	10.6	344
Boot	85	5.7	44.6	6.3	56.6	28.0	494
	50	4.5	40.4	5.7	50.6	13.3	263
Anthesis	85	14.6	60.7	11.0	86.3	28.9	335
	50	10.2	47.0	8.7	65.9	13.0	196
Check	85	23.8	68.4	14.2	106.4	28.6	269
	50	15.7	54.5	11.1	81.3	13.5	166

VICTORIA (SUSCEPTIBLE)

Seedling	85	1.0	36.8	3.8	41.6	22.1	532
	50	1.2	30.6	2.8	34.6	13.8	399
Boot	85	5.6	45.9	8.7	60.2	27.2	452
	50	5.0	40.6	7.5	53.1	15.4	290
Anthesis	85	15.7	59.3	12.5	87.5	29.6	338
	50	11.8	46.3	9.7	67.8	15.1	223
Check	85	28.4	63.7	20.5	112.6	30.6	272
	50	19.8	50.4	16.7	86.9	16.3	188

BOND (NEARLY IMMUNE)

Seedling	85	19.6	59.4	14.4	93.4	28.2	302
	50	14.3	41.8	10.5	66.6	15.1	227
Boot	85	20.1	61.5	15.1	96.7	28.6	296
	50	15.9	45.9	13.3	75.1	16.5	220
Anthesis	85	21.8	64.5	15.8	102.1	29.3	290
	50	18.0	47.7	14.1	79.8	17.6	221
Check	85	22.8	65.6	15.8	104.2	29.7	285
	50	18.4	50.4	14.8	83.6	17.9	214

[8] The significance of the mean squares was determined by calculating the ratio of the larger mean square to the smaller. This ratio is designated as F by Snedecor. As the value of F becomes larger the significance becomes greater, depending upon the degrees of freedom in the two mean squares. With 3 and 12 degrees of freedom the least value of F that can be considered highly significant is 6.0, and with 1 and 12 degrees of freedom the least value that can be considered highly significant is 9.3.

TABLE 8.—*Mean yield and water requirement*[1] *of Markton, Victoria, and Bond Oats infected with Puccinia coronata avenae at different stages of development, in 1933*

GRAIN

Stage at initial infection	Markton (susceptible)		Victoria (susceptible)		Bond (nearly immune)	
	High soil moisture	Low soil moisture	High soil moisture	Low soil moisture	High soil moisture	Low soil moisture
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Seedling	2.1	3.2	3.5	6.1	86.0	77.7
Boot	23.9	28.7	19.7	25.3	88.2	86.4
Anthesis	61.3	65.0	55.3	59.6	95.6	97.8
Check	100.0	100.0	100.0	100.0	100.0	100.0

STRAW

Seedling	45.0	50.8	57.8	60.7	90.5	82.9
Boot	65.2	74.1	72.1	80.6	93.8	91.1
Anthesis	88.7	86.2	93.1	91.9	96.8	94.6
Check	100.0	100.0	100.0	100.0	100.0	100.0

ROOTS

Seedling	21.8	24.3	18.5	16.8	91.1	70.9
Boot	44.4	51.4	42.4	44.9	95.6	89.9
Anthesis	77.5	78.4	61.0	58.1	100.0	95.3
Check	100.0	100.0	100.0	100.0	100.0	100.0

WATER REQUIREMENT

Seedling	195.9	207.2	195.6	212.3	106.0	106.1
Boot	183.6	158.4	166.2	154.3	103.9	102.8
Anthesis	124.5	118.1	124.3	118.6	101.8	103.3
Check	100.0	100.0	100.0	100.0	100.0	100.0

[1] Percentage of that of rust-free check.

TABLE 9.—*Analysis of the variation in yield and water requirement of Markton, Victoria, and Bond oats infected with physiologic form 7 of Puccinia coronata avenae, in 1933*

[Values in boldface type are highly significant (level of significance beyond Fisher's 1-percent point, odds 99 to 1 or greater)]

MARKTON (SUSCEPTIBLE)

Source of variation	Degrees of freedom	Mean squares				
		Grain	Straw	Roots	Total weight	Total water requirement
Experimental error	12	0.17	0.58	0.23	2.88	185.42
Between stages	3	**416.52**	**1,664.36**	**96.82**	**3,905.79**	**54,926.85**
Between moistures	1	**61.20**	**368.20**	**12.22**	**940.75**	**129,190.80**
Interaction	3	**21.04**	**41.63**	**2.09**	**142.15**	**3,692.73**

VICTORIA (SUSCEPTIBLE)

Experimental error	12	0.60	1.86	0.65	5.46	211.72
Between stages	3	**556.68**	**582.02**	**213.26**	**3,776.76**	**56,462.13**
Between moistures	1	**50.96**	**432.66**	**23.23**	**1,072.21**	**23,507.50**
Interaction	3	**19.21**	**21.76**	2.14	**104.39**	**1,291.14**

BOND (NEARLY IMMUNE)

Experimental error	12	1.76	2.03	0.85	11.19	178.89
Between stages	3	**14.53**	**46.42**	**6.54**	**170.69**	204.32
Between moistures	1	**92.03**	**1,237.13**	**21.68**	**2,443.52**	**24,883.25**
Interaction	3	.38	1.38	1.85	8.56	**16.61**

The 1933 yields were much lower than those of 1930, probably because of the excessive heat. A 50-percent infection with form 7 on Markton caused a decrease in yield and an increase in water requirement smaller than those caused by a 100-percent infection with form 1 in 1930. Crown rust infection again reduced the yield of grain more than that of any other part of the plant; the roots were the parts next most affected, and the straw, or remaining plant parts, were the least affected. Rust infection caused a greater reduction in the yield of the susceptible Markton oats when grown at 85-percent soil moisture than when grown at 50 percent (fig. 8). The

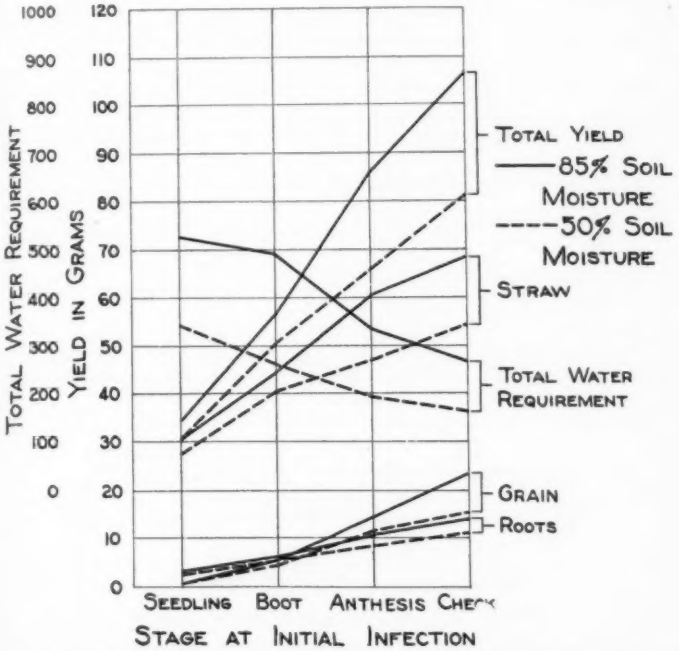

FIGURE 8.—Yield and water requirement of a susceptible selection of Markton oats grown at 85- and 50-percent soil moisture and initially infected in seedling, boot, and anthesis stage with form 7 of crown rust, in 1933.

increase in total water requirement due to infection was greater at 85-percent soil moisture for those plants initially inoculated in the boot and anthesis stages but lower when inoculations were started in the seedling stage. Plants growing at a soil moisture of 50 percent regularly yielded significantly less than those growing at 85-percent soil moisture, regardless of the time of initial infection. Low soil moisture decreased the yield of grain more than that of any other plant structure, but caused an even more significant decrease in the water requirement of all plants.

The pure-line selection of Victoria used in 1933 was susceptible to form 7. This was not the same reaction as that shown by the parent variety or the pure-line selection used in 1930. The selections, how-

ever, appeared to be identical morphologically. The effect of infection with form 7 on the yield and water requirement of the susceptible pure line of Victoria (fig. 9) was very similar to the effect on Markton. The increase in total water requirement for each variety was greater at 85-percent soil moisture for those plants initially inoculated in the boot and flower stages, but lower when inoculations were started in the seedling stage. The decrease in yield due to rust infection was, with two exceptions, regularly greater at the higher soil moisture, although the differences usually were small. Both varie-

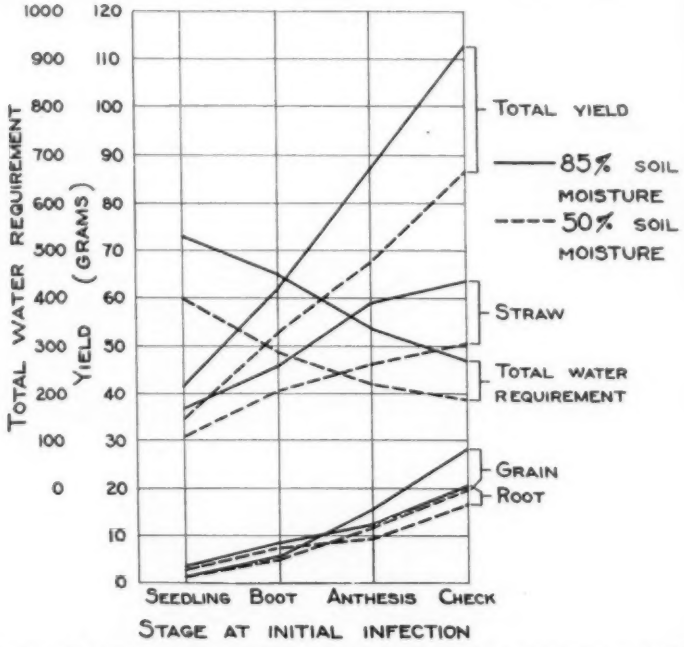

FIGURE 9.—Yield and water requirement of a susceptible selection of Victoria oats grown at 85- and 50-percent soil moisture and initially infected in the seedling, boot, and anthesis stage with form 7 of crown rust, in 1933.

ties, with one exception, regularly showed significantly higher yields at the higher soil moisture.

The yield and water requirement of the nearly immune pure-line selection of Bond, when infected in the various stages with form 7, is illustrated in figure 10. Although the quantity of inoculum applied was always equal to if not greater than that applied to the susceptible Markton and Victoria selections, the percentage of infection on Bond was consistently about 15 and never more than 30. As previously mentioned, uredia were entirely absent, chlorotic or slightly necrotic flecks being the only macroscopic evidence of infection. This slight and resistant type of infection, however, evidently caused a significant retardation in the development and yield of the plants.

The experiments conducted in 1933 show that infection with form 7 decreased the yield of the susceptible pure lines of Markton and Victoria to a relatively greater extent at a soil moisture of 85 percent than at a soil moisture of 50 percent. The lower soil moisture significantly reduced the yield of all plant parts of the susceptible selections, but not so much as did infection initiated in either the seedling or the boot stage of the host. Crown rust affected the yield of grain of these same selections more profoundly than did the lower soil moisture, while in the case of the Bond selection the low soil

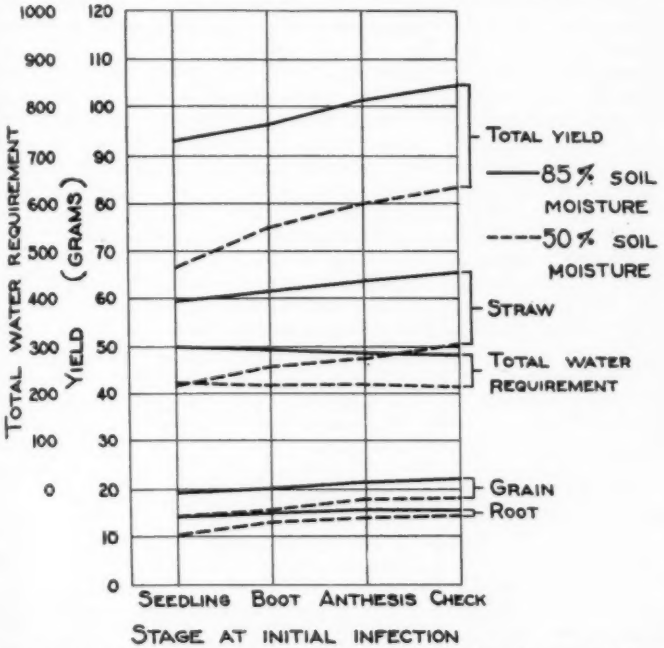

FIGURE 10.—Yield and water requirement of a nearly immune selection of Bond oats grown at 85- and 50-percent soil moisture and initially infected in the seedling, boot, and anthesis stage with form 7 of crown rust, in 1933.

moisture affected the yield more than did the rust infection, even when the latter was initiated in the seedling stage. In general, on both susceptible and resistant selections the yield of grain was most affected by rust, the yield of roots somewhat less so, and the yield of straw least. Rust infection caused a higher water requirement on both susceptible and resistant selections, but the effect was many times greater on the former; and the earlier the infection of either, the more pronounced the effect. The lower soil moisture, although it greatly decreased the yields of all series, brought about a much lower water requirement.

EFFECT OF CROWN RUST INFECTION ON THE RATIO OF ROOTS TO STRAW

Crown rust infection, as it occurred on the plants studied under greenhouse conditions in 1930 and 1933, was limited primarily to the leaf blades and leaf sheaths, with some infection frequently present on the stems and panicles. Infection was not observed on the grains, although the glumes were often slightly infected. The roots obviously were free from rust. All of the tissues included as straw were more or less infected; and, although most of the food used by the plant is manufactured or elaborated in these same tissues, the yield of straw was least affected by the rust, while the yield of rust-free grain and roots was greatly reduced.

Crown rust apparently affects the yield of grain and roots indirectly by reducing the food supply available for translocation to these parts. Long (*5*) found that a heavy infection of crown rust on a susceptible oat variety reduced the photosynthetic activity of the host 52 percent. Her data indicate that rust infection interfered seriously with the accumulation of reducing sugars and impaired by more than 50 percent the ability of infected tissues to elaborate carbohydrates. Any factor thus affecting the photosynthetic activity of the host would tend to decrease the ratio of the roots to the tops or straw because of the diminished translocation of food materials to the roots. Turner (*10*) reports that barley plants grown in the shade had a lower ratio of roots to tops than similar plants grown in sunlight. Crown rust brings about a reduction in the yield of all plant parts, but most reduction occurs in those parts most distant from the point of infection, which in this case are the parts farthest from the source of elaborated foods, as indicated in table 10, which shows the ratio of roots to straw in the experiments conducted in 1930 and 1933.

TABLE 10.—*Effect of crown-rust infection on root and straw ratios*

Stage at initial infection	Weight of roots as percentage of the weight of straw							
	1930		1933					
			Markton		Victoria		Bond	
	Markton	Victoria	High soil moisture	Low soil moisture	High soil moisture	Low soil moisture	High soil moisture	Low soil moisture
Seedling	2.8	16.9	10.1	9.7	10.3	9.2	24.2	25.1
Boot	5.7	19.5	14.1	14.1	19.0	18.5	24.6	29.0
Anthesis	7.6	26.6	18.1	18.5	21.1	21.0	24.5	29.6
Dough	20.8	30.6						
Check	22.8	31.8	20.8	20.4	32.2	33.1	24.1	29.4

The ratio of the roots and grain to straw and the ratio of roots to tops were reduced in proportion to the severity and total duration of infection. In 1930, with a 100-percent infection, the ratio of roots to straw of the susceptible Markton selection was reduced from 22.8 percent for the rust-free plants to 2.8 percent for those initially infected in the seedling stage, while the corresponding reduction for the resistant Victoria selection was from 31.8 to 16.9 percent. There is

a consistent relation between the total duration of infection and the reduction in the ratio of roots to straw for both the susceptible and resistant selections, although the reduction is much more pronounced in the susceptible selections.

The 1933 data for these crown-rust susceptible selections of Markton and Victoria were very similar to those obtained for these selections in 1930, except that the reduction in the ration of roots to straw was not so great. The relation between the duration of infection and the reduction of the ratio of roots to straw is clearly evident at both soil moistures. When infection was initiated in the seedling stage the ratio of roots to straw was smaller at the lower soil moisture, but as initial infection was delayed the ratio of roots to straw tended to become greater at the lower soil moisture. Rust had very little effect on the ratio of roots to straw of the nearly immune Bond selection, while the lower soil moisture brought about a consistent increase in the ratio of roots to straw.

The ratio of roots to tops or straw is doubtless of great importance under field conditions. Heavy epiphytotics of crown rust usually are preceded by a period of wet weather with attendant high humidity and soil moisture. These conditions, while highly favorable for rust, are also favorable for top growth, and as stated by Loomis (*6*), root development suffers. Then as rust appears and increases, the ratio of roots to tops is still further decreased by the effect of the fungus. This results in a topheavy plant with luxuriant foliage, heavily infected with rust, and with a dwarfed root system. Such a plant is at a great disadvantage when, as is often the case late in the season, deficient soil moisture becomes a limiting factor. The lack of a sufficient root system directly reduces the ability of the plant to obtain moisture, while, at the same time, as a result of the rust infection, its water requirement is greatly increased. The food supply is much less because of the dwarfed root system and limited water supply, while the fungus interferes directly with the photosynthetic processes of the infected plant. The pathogene, growing at the immediate source of elaborated plant food, is in a position to satisfy its own needs before translocation takes place. In consequence, the grain and roots, being farthest from these infected tissues but dependent upon them for their food supply, suffer the most serious loss.

DISCUSSION AND CONCLUSIONS

The results of these investigations in 1928, 1930, and 1933 indicate that the effect of crown rust on photosynthesis, date of ripening, total yield, and water requirement of susceptible and resistant varieties of oats varies with the degree and type of infection, the stage of growth of the host, and the duration of infection. Crown rust infection affected significantly the yield and water requirement of both susceptible and resistant varieties when it appeared at any time before the dough stage of host development. The longer the duration and the more abundant the infection the greater was the decrease in yield and the increase in water requirement. Susceptible varieties that become heavily infected early and so remain until maturity may yield no seed at all, while similar infection initiated during anthesis may cause a 50-percent reduction in the yield of grain. The yield and water requirement of a resistant variety are much less affected. An

infection with a few small uredia and much necrosis on the resistant Victoria selection in 1930 reduced the yield of grain approximately one-half as much as did an equal amount of infection with many large uredia and no necrosis on Markton. A resistant variety showing only chlorotic or necrotic flecks or a few small uredia in necrotic areas will apparently be damaged much less than a susceptible variety with an equal amount of infection in which uredia are abundant but with no surrounding necrosis and little chlorosis. For a given area chlorotic infection apparently causes less damage to the host than does a necrotic one, while an infection characterized by abundant uredia unaccompanied by any surrounding necrosis and with little chlorosis causes much more damage than either of the former. When the percentages of infection are equal, the effect of all infection types on the amount of functioning leaf area is probably about the same, but their effect on the metabolism of the host is evidently very different.

Under field conditions the amount of infection on a resistant or nearly immune variety is automatically restricted because of the partial or complete elimination of the source of inoculum for secondary and later infections. As the acreage of a resistant variety is increased the amount of inoculum available for secondary and later infections becomes less, while with a susceptible variety the amount of inoculum and the resulting infection become greatly increased. This particular advantage of a resistant variety may be easily overlooked in nursery tests where resistant and susceptible sorts are grown near each other. There resistant varieties usually are subject to severe infection from neighboring susceptible varieties and their yield may be reduced to the point where it does not surpass that of the susceptible ones, while under field conditions the resistant varieties might be far superior.

Reduced yield of grain was expressed in terms of fewer and lighter kernels. Infection initiated on susceptible selections in or before the boot stage caused partial or complete absence of kernels, depending upon the amount of infection; while infection initiated during anthesis affected mainly the size of the kernels. On resistant selections, rust infection did not appear to cause much sterility but chiefly affected the weight per kernel. The decrease in yield of grain of susceptible selections, due to rust infection, was slightly greater at the higher soil moisture. A combination of heavy rust infection and low soil moisture apparently will cause a much greater loss in yield than either one alone, even though the percentage of loss caused by the rust be slightly greater at the higher soil moisture.

Crown rust infection increased the water requirement of both susceptible and resistant plants in about the same manner and degree that it decreased the yield of grain. Lowering the soil moisture, on the other hand, decreased the water requirement. The decrease in water requirement of the susceptible selections, due to the lower soil moisture, was not sufficient to compensate for the increase caused by rust infection initiated in the seedling or boot stages but was more than equal to the increase due to infection initiated during anthesis. In the case of the resistant selection the lower soil moisture reduced the water requirement 25 percent, while rust infection initiated in anthesis increased it only 6 percent.

Rust infection probably affects the water requirement directly by mechanical injury and indirectly by its effect on the metabolism of the host. There was a perceptible increase in the water consump-

tion of initially infected plants about the time the uredia ruptured the epidermis. These infected plants continued to use more water than similar rust-free plants for a period of about 2 weeks, when the infected tissues began to die. The increased water requirement of the infected plants was mostly due to the reduction in yield, but since the retardation of growth was caused by rust, this increased water requirement and lower total consumption of water was indirectly a result of rust infection.

The data presented in this paper are of interest in that they permit of a more accurate estimation of the amount of damage that may result from a moderate or heavy infection of crown rust under field conditions. There is probably a tendency to underestimate the damage caused by crown rust because the parts of the plant actually infected suffer less than the grain and roots, which are not infected. The fact that oat plants heavily infected with crown rust may, under favorable conditions, retain a rather luxuriant foliage often causes the layman to believe that little damage is done to the plant, when, in reality, the yield of grain is greatly reduced by the rust. These data also emphasize the importance of considering the degree and duration of infection when evaluating the damage likely to occur as a result of rust infection.

Although it is evident that most of the loss caused by crown rust may be prevented by dusting with sulphur at proper intervals, the most desirable method of combating the disease is obviously that of developing rust-resistant varieties. The value of any high-yielding selections or varieties endowed with Victoria's resistance to form 1 should not be overlooked, while near immunity, such as that exhibited by the Bond selection, affords virtually complete protection from crown rust.

SUMMARY

Iomine oats growing under field conditions in 1928 and showing a 100-percent infection artificially initiated on June 9 produced 44.2 percent as much grain as sulphur-dusted oats of the same variety with 11.7 percent infection. Oats of the same variety with 24-percent infection yielded 74.1 percent as much grain as nearly rust-free ones. There was evident a strong positive correlation between early initial infection and reduction in yield and weight per bushel.

Early infection retarded the date of heading of Iomine plants, although these same plants showed premature ripening before the later heading, less rusted plants. The premature ripening of the heavily rusted plants was apparently due to their greater susceptibility to injury from the excessively hot dry weather of early July.

Two pure lines of oats, selected from Markton and Victoria, the former completely susceptible and the latter highly resistant, were grown to maturity in the greenhouse in 1930 and subjected to a 90- to 100-percent infection of form 1 of crown rust. A study was made of the relation of the length of the infection period to yield and water requirement.

Crown rust infection initiated on plants of both selections in the seedling, boot, or anthesis stage of growth resulted in a significant reduction in yield and increase in water requirement. Infection started in the dough stage of growth had no significant effect on either selection.

The reduction in yield and increase in water requirement were positively correlated with the length of the infection period.

Infection initiated in the seedling and boot stages completely checked the production of grain on the susceptible selection, while the yield of the resistant one was 52.5 and 69.2 percent, respectively, as much as that of the rust-free plants.

The reduction in grain yield was due to the production of fewer and lighter kernels. Rust infection increased the percentage of hulls in the grain.

Except where the yield of grain was entirely inhibited, the yield of roots was reduced most and that of the straw least.

Susceptible plants first infected in the seedling stage used 290.8 percent more water per unit of dry weight than rust-free plants, while resistant plants used only 39.9 percent more.

Three pure lines of oats, selected from Markton, Victoria, and Bond, the first two completely susceptible and the last nearly immune, were grown to maturity at two soil moistures in 1933. The susceptible plants were subjected to a 40- to 70-percent infection with form 7 of crown rust, while the amount of infection on the nearly immune plants was 15 to 30 percent.

The lighter infection in 1933 reduced the yield and increased the water requirement of the susceptible selections in a manner similar to but less than the heavy infection in 1930.

Rust infection tended to have a greater effect on the yield and water requirement of the susceptible selections at the higher soil moisture, while on a nearly immune Bond selection the effect was greater at the lower soil moisture.

The lower moisture significantly reduced the yield of all plant parts. With the susceptible selections this effect was less than that caused by infection initiated in the seedling or boot stage, but greater when infection was initiated in the anthesis stage, while in the case of the resistant Bond selection the lower soil moisture regularly affected the yield more than did the rust infection. Lowering the soil moisture also decreased the water requirement of all plants, both rusted and rust-free.

The ratio of roots to tops was greatly decreased by rust infection, the decrease being in proportion to the duration and severity of infection.

LITERATURE CITED

(1) Fisher, R. A.
1932. Statistical methods for research workers. Ed. 4, rev., 307 pp., illus. Edinburgh and London.

(2) Immer, F. R., and Ausemus, E. R.
1931. A statistical study of wheat and oat strains grown in rod-row trials. Jour. Amer. Soc. Agron. 23: 118–131.

(3) ——— and Stevenson, F. J.
1928. A biometrical study of factors affecting yield in oats. Jour. Amer. Soc. Agron. 20: 1108–1119.

(4) Johnston, C. O., and Miller, E. C.
1933. Effect of leaf-rust infection on water economy and growth of two wheat varieties. (Abstract) Phytopathology 23: 19.

(5) Long, F. L.
1919. The quantitative determination of photosynthetic activity in plants. Physiol. Researches 2: 277–300.

(6) Loomis, W. E.
1933. Growth-differentiation balance vs. carbohydrate-nitrogen ratio. Amer. Soc. Hort. Sci. Proc. (1932) 29: 240–245.

(7) MURPHY, H. C.
1935. PHYSIOLOGIC SPECIALIZATION IN PUCCINIA CORONATA AVENAE. U.S. Dept. Agr. Tech. Bull. 433, 48 pp.

(8) ———
1935. EFFECT OF CROWN RUST ON YIELD, WATER ECONOMY, AND COMPOSITION OF OATS. (Abstract) Phytopathology 25: 28–29.

(9) SNEDECOR, G. W.
1934. CALCULATION AND INTERPRETATION OF ANALYSIS OF VARIANCE AND CO-VARIANCE. 96 pp. Ames, Iowa. (Iowa State Col. Div. Indus. Sci., Monog. 1.)

(10) TURNER, T. W.
1922. STUDIES OF THE MECHANISM OF THE PHYSIOLOGICAL EFFECT OF CERTAIN MINERAL SALTS IN ALTERING THE RATIO OF TOP GROWTH TO ROOT GROWTH IN SEED PLANTS. Amer. Jour. Bot. 9: 415–445.

(11) WEAVER, J. E.
1916. THE EFFECTS OF CERTAIN RUSTS UPON THE TRANSPIRATION OF THEIR HOSTS. Minn. Univ. Bot. Studies 4: 379–406, illus.

(12) WEISS, F.
1924. THE EFFECT OF RUST INFECTION UPON THE WATER REQUIREMENT OF WHEAT. Jour. Agr. Research 27: 107–118.

FACTORS AFFECTING THE ABSORPTION OF SELENIUM FROM SOILS BY PLANTS[1]

By ANNIE M. HURD-KARRER[2]

Associate physiologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

The cause of a serious disease of livestock in certain restricted areas of the Great Plains has recently been traced by the United States Department of Agriculture, in cooperation with the agricultural experiment stations of certain of the affected States, to ingestion of selenium contained in the vegetation (*3*).[3] That selenium is absorbed readily by plants which thereupon become toxic to animals has been established experimentally (*10*). Some of the factors affecting this absorption are reported in the present paper, which supplements an earlier discussion (*7*) of the toxicity of selenium to plants.

METHODS[4]

The plants, mostly wheat (Hard Federation), were grown in soil to which selenium had been added in the form of sodium selenate ($Na_2SeO_4.10H_2O$). Solutions containing the predetermined quantities of selenium, expressed as parts per million by weight of the soil, were added with thorough mixing to insure uniform distribution.

Estimates of injury to the plants (indicated by number of plus signs in the tables) were based on the occurrence and extent of the snow-white chlorosis and stunting characteristic of wheat plants damaged by sodium selenate (fig. 1). The selenium taken up by the plants, exclusive of the roots, was determined [4] quantitatively by the distillation method (*11*) and expressed as parts per million of the air-dry weight of the material. Colorimetric estimations [4] were in agreement with the results obtained by the distillation method.

RESULTS

COMPARATIVE SELENIUM ABSORPTION BY DIFFERENT CROPS

A number of different crops were grown in greenhouse benches at the Arlington Experiment Farm, Rosslyn, Va., in the local Keyport clay loam into which sodium selenate was mixed at a rate of 5 parts per million of selenium. The average temperature of the greenhouse was near 20° C. for the first 2 months, at the end of which period some of each lot of plants (except sorgo and bromegrass, which were cut a month later) were cut and analyzed (table 1). This temperature was too low to permit good growth of the high-temperature plants, millet, sorgo, and corn. Of the 17 crops, only sorgo showed specific symptoms of selenium injury, i. e., snow-white chlorosis, often tinged with pink.

[1] Received for publication Jan. 8, 1935; issued May 1935.

[2] The writer is indebted to A. G. Johnson, of the Division of Cereal Crops and Diseases, and to H. G. Byers, M. J. Horn, T. D. Rice, and W. O. Robinson, of the Bureau of Chemistry and Soils, for helpful cooperation.

[3] Reference is made by number (italic) to Literature Cited, p. 426.

[4] The quantitative selenium determinations were made by A. Van Kleeck, under the direction of H. G. Byers, of the Bureau of Chemistry and Soils. The colorimetric estimations were made by M. J. Horn with his modification of the Schmidt method (*5*). Analyses of the soils for sulphur were made by J. B. Martin under the direction of E. C. Shorey of the Bureau of Plant Industry.

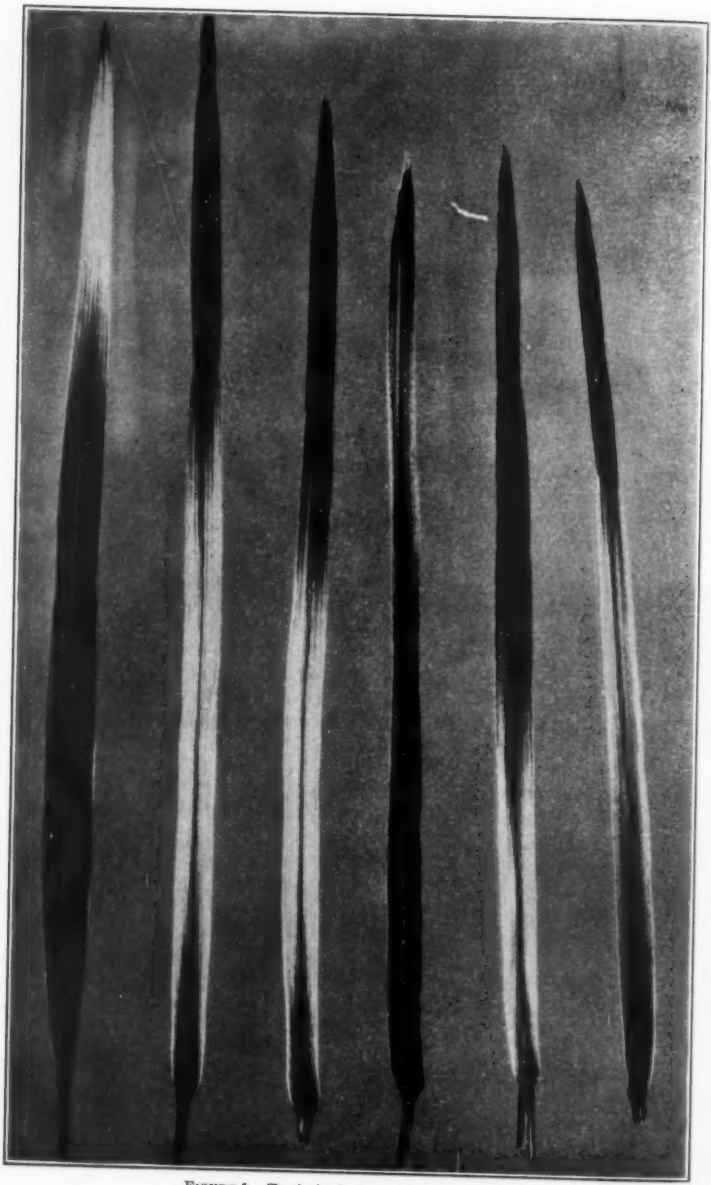

FIGURE 1.—Typical selenium chlorosis on wheat leaves.

TABLE 1.—*Comparative absorption of selenium by young plants of different crops grown in the greenhouse with 5 parts per million of selenium as sodium selenate added to the soil (Keyport clay loam)*

Crop	Condition	Selenium in plants	Crop	Condition	Selenium in plants
		P. p. m.			*P. p. m.*
Cruciferae:			Gramineae:		
Mustard	Normal	1, 240	German millet	Growth slow	590
Broccoli	do	1, 180	Oats	Normal	535
Compositae:			Wheat	do	470
Sunflower	Leaves spotted	790	Barley	do	450
Linaceae:			Proso millet	Growth slow	285
Flax	Normal	685	Corn	do	275
Leguminosae:			Crested wheatgrass	Normal	255
Sweetclover	do	645	Bromegrass	do	200
Alfalfa	do	560	Sorgo	Growth slow, leaves chlorotic and pink.	130
Pea	do	560			
Chenopodiaceae:					
Spinach	do	315			

The data in table 1 show the greatest accumulation of selenium in the two representatives of the Cruciferae—mustard and broccoli. One of the outstanding characteristics of plants of this family is their capacity for absorbing large quantities of sulphur from the soil for the synthesis of sulphur-containing compounds, such as the glucoside sinigrin, from which mustard oil is derived. If the previously suggested explanation (7) of sulphur-selenium antagonism is correct (a theory based on the assumption of substitution of selenium for sulphur in some synthesized compound in the plant) it would seem likely that the greater accumulation of selenium in the Cruciferae is to be accounted for by their capacity for high sulphur absorption. On this assumption the legumes that absorb sulphur in large quantities by virtue of their high protein content might also be expected to accumulate selenium readily, whereas the Gramineae with a low sulphur requirement should absorb less. The data show that the three representatives of the Leguninosae were relatively high in selenium, exceeding in amount that found in any of the Gramineae except German millet, but containing less than flax and sunflower.

COMPARATIVE SELENIUM ABSORPTION FROM KEYPORT CLAY LOAM AND PIERRE CLAY

Sodium selenate was much more toxic to wheat growing in Pierre clay than in Keyport clay loam. In the latter soil about 15 p. p. m. of selenium was required for distinct chlorosis and over 30 p. p. m. for fatal injury (fig. 2, *A*), whereas in the former the addition of only 3 p. p. m. produced definite traces of chlorosis and 10 p. p. m. was often fatal (fig. 2, *B*).

Comparative analyses of the leaves of plants grown subsequently in these same pots of soil indicated that the greater toxicity of selenium in the Pierre clay was associated with greater availability to the plant, more selenium being taken up than from the same concentrations in the Keyport clay loam. Thus the data in table 2 show that more was absorbed from 5 p. p. m. added to the former soil than from 10 p. p. m. in the latter, and the amount taken up from 10 p. p. m. in the former soil was of the same order of magnitude as that absorbed from 30 p. p. m. in the latter. The Pierre clay was an alkaline black gumbo soil, containing about 12 percent calcium carbonate, brought

FIGURE 2.—Toxicity of sodium selenate to wheat plants 5 weeks old in different soils. Numbers on pots show parts per million of selenium: *A*, Plants in Keyport clay loam, not visibly affected, by 10 parts per million of selenium, chlorotic and stunted with 20 and 30 parts per million; *B*, plants in Pierre clay normal with 1 part per million, chlorotic and stunted with 5 parts per million, dead with 10 parts per million; *C*, plants in greenhouse potting soil (clay loam) to which 20 percent of quartz sand was added, chlorotic and stunted with 10 and 20 parts per million of selenium and dead with 30 parts per million.

from a naturally seleniferous area in Gregory County, S. Dak., for the experiments. It had a trace of naturally occurring selenium, but the quantity (less than 1 p. p. m.) was so small as to produce but 15 p. p. m. in the control plants. However, for strict comparisons of the availability of the added selenate this amount should be subtracted from the total found in the plants in the Pierre clay. Thus 945 and 1,335 p. p. m. selenium were absorbed from 10 and 20 p. p. m., respectively, in this soil as compared with 380 and 530 from the corresponding additions of selenate to the clay loam.

TABLE 2.—*Absorption of selenium by wheat from sodium selenate added to Keyport clay loam and Pierre clay*

Selenium added to soil (p. p. m.)	Keyport clay loam			Pierre clay		
	Condition of plants	Degree of chlorosis	Selenium in plants	Condition of plants	Degree of chlorosis	Selenium in plants
			P. p. m.			*P. p. m.*
0	Normal	0	[1] Trace	Normal	0	15
1				do	0	325
3				Almost normal	+	330
5				Stunted	++	450
10	Normal	0	380	Severely stunted	+++	960
20	Stunted	++	530	Withered, almost dead	++++	1,350
30	Severely stunted	+++	1,000			
35	do	+++	1,120			

[1] The distillation method of analysis indicated the presence of a trace of selenium in these plants, but none was detected by the codeine-sulphate method.

The differences in the amounts of selenium absorbed from the two soils were not due to differences in their sulphur content (*7*), for analyses showed but 0.003 percent of water-soluble sulphur in each. Total sulphur was 0.03 percent in the Pierre clay and 0.06 percent in the Keyport clay loam. Nor was hydrogen-ion concentration the determining factor, for increasing the alkalinity of the slightly acid Keyport clay loam (pH 6.7) to that of the Pierre clay (pH 8.1) by adding calcium carbonate did not increase the toxicity of the sodium selenate. In fact, the calcium carbonate application (1 part in 500 parts of soil) improved the condition of the plants. It has been suggested [5] that the difference might be due to the difference in composition of the soil colloids. The high molecular ratio of silica to the sum of the alumina and iron in the colloids of the Pierre clay, 3.5, as compared with that of the Keyport clay loam, 1.9, would result in more insoluble combination and decreased availability of the selenium in the salt added to the soil with the lower ratio (*12*).

SELENIUM ABSORPTION AS A FUNCTION OF THE CONCENTRATION OF AVAILABLE SULPHUR IN THE SOIL

As previously reported (*6*), the detection by J. E. McMurtrey, Jr., of the Bureau of Plant Industry, of a resemblance between certain aspects of selenium chlorosis and the chlorosis resulting from sulphur deficiency led to the discovery that the toxicity of sodium selenate to wheat plants is conditioned by the quantity of available sulphur or sulphates (*7*). The comparative amounts of sulphur required

[5] This suggestion was made by H. G. Byers, in whose division of the Bureau of Chemistry and Soils the colloid ratios were determined.

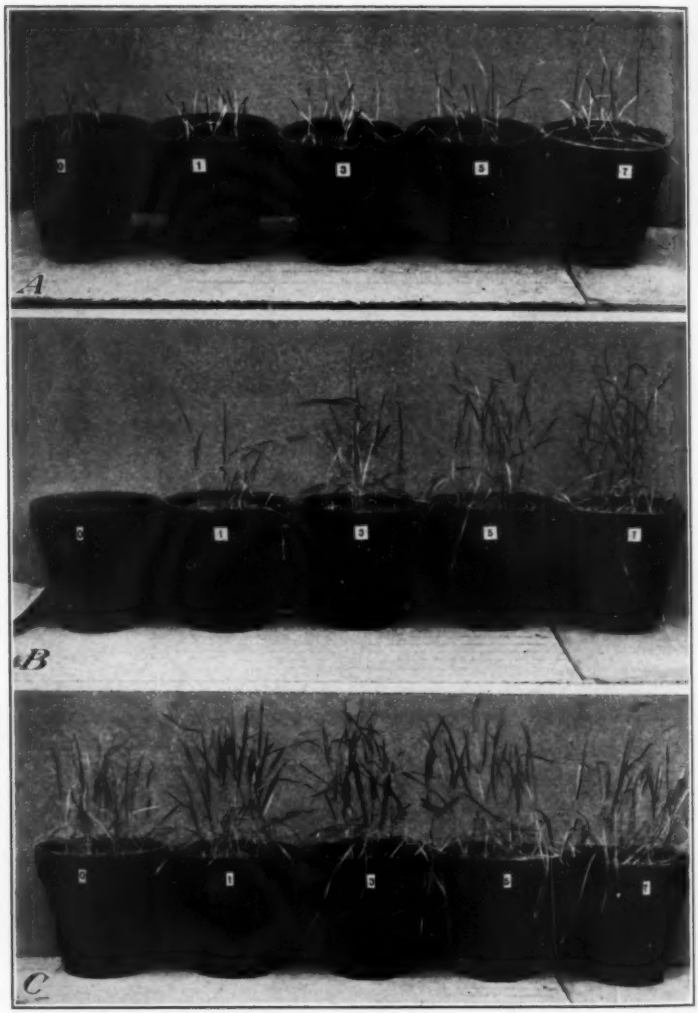

FIGURE 3.—Comparative degrees of inhibition of selenium (20 p. p. m.) injury by various amounts of sulphur in two different soils. Numbers on pots indicate grams of sulphur added to 6,000 g of soil. (Abnormally rapid development of the plants was due to lateness of the season, the grain having been sown April 26): *A*, One-month-old plants in Pierre clay injured by selenium but progressively improved as the amount of added sulphur was increased; *B*, same plants as in *A* 1 month later, dead with no sulphur treatment, severely injured with but 1 g, slightly injured with 3 g, and almost normal with 5 and 7 g; *C*, 2-month-old plants in Keyport clay loam, severely injured with no sulphur treatment, slightly chlorotic with 1 g, uninjured with 5 and 7 g.

for prevention of the symptoms produced by the addition of 20 p. p. m. selenium as sodium selenate to the two soils, Pierre clay and Keyport clay loam, are shown in figure 3. In the former soil the addition of 20 p. p. m. of selenium was fatal without the application of sulphur (*A, B*), but in the latter soil it was merely injurious (*C*). As the quantity of sulphur applied to the Pierre clay series was increased from 1 to 7 g, symptoms of injury were progressively reduced. In the Keyport clay loam, where sodium selenate was less available to the plants (table 2), less sulphur was required for a given degree of control.

Table 3 gives analyses of plants of various soil experiments dealing with the control of selenium injury by sulphur. These analyses show that inhibition of injury is accompanied by a reduction in the quantity of selenium taken into the plant. In every experiment the quantities of selenium taken up and the resulting degrees of injury bore an inverse relation to the amount of sulphur added to the soil.

TABLE 3.—*Effect of elemental sulphur applications on absorption of selenium by wheat plants from sodium selenate added to Keyport clay loam and Pierre clay in the greenhouse (second sowings)*

Type of soil	Selenium added to soil	Sulphur added to soil		Selenium in plants	Degree of selenium injury to plants
		Per pot of 6,000 g	Rate of application		
	P. p. m.	*Grams*		*P. p. m.*	
Keyport clay loam	20	0		480	++++
		4	1:1,500	360	+
		5	1:1,200	230	0
Pierre clay	5	0		450	+
		10	1: 600	150	0
Do	10	0		960	+++
		5	1:1,200	425	0
Do	20	0		1,350	+++++
		2	1:3,000	850	++
		6	1:1,000	800	+
		15	1: 400	600	0

Gypsum ($CaSO_4$) also was effective in reducing the selenium taken up by wheat plants, as shown by various pot tests and also by some results obtained with field plots at the Arlington Experiment Farm. The soil in these plots was treated in the fall with sodium selenate, at the rate of 2 p. p. m. of selenium, mixed in to a depth of 6 inches. Two of them received elemental sulphur also, at the rate of 1 part sulphur to 1,200 parts soil, and two others received quantities of gypsum containing the same amount of sulphur. Winter wheat was then sown. When sampled the following spring the plants contained from 50 to 110 p. p. m. of selenium except where sulphur had been added. For these the corresponding figures were 7.5 and 5 p. p. m. where the sulphur had been added as gypsum, and 2 p. p. m. for each of the plots that had received elemental sulphur. Evidently, both elemental sulphur and gypsum are effective in inhibiting selenium absorption in the field as well as under greenhouse conditions.

The fact that gypsum was so effective in reducing absorption of selenium precluded any possibility that the inhibiting action of elemental sulphur was a consequence of its acidification of the soil. Other evidence that the phenomenon occurred independently of the

acidifying effect was the complete control of the severe symptoms produced by 5 p. p. m. of selenium in the alkaline Pierre clay by the addition of an amount of sulphur (1 part in 600 parts of soil) which only slightly increased its acidity, that is, from pH 8.1 to 7.9 in one experiment and from 8.3 to 7.8 in another.[6] Moreover, rendering the Keyport clay loam alkaline by adding calcium carbonate (1 part in 500 parts soil) did not lessen the effectiveness of sulphur applications. Further evidence of the unimportance of acidity in selenium-sulphur antagonism was obtained incidentally in numerous experiments conducted with nutrient solutions, some of which are referred to in a previous publication (*7*).

To determine whether excess sulphur reduces absorption of naturally occurring selenium as well as that added as sodium selenate, plants were grown in the greenhouse in an untreated Pierre clay loam [7] containing 4 p. p. m. of naturally occurring selenium. Others were grown with elemental sulphur added at the rate of 1 part in 1,200 parts of this soil. The plants in the untreated soil were found to contain 450 p. p. m. of selenium, those in the sulphur-treated soil 15 p. p. m. Analyses of plants from other pots by M. J. Horn with the colorimetric codeine-sulphate method (*5*) indicated a similar reduction.

SELENIUM TOXICITY WITH DIFFERENT ADMIXTURES OF SAND TO SOIL

The addition of 20 percent of quartz sand to the local Keyport clay loam increased the toxicity of sodium selenate to the extent that 10 p. p. m. of selenium, an otherwise harmless concentration in this soil (fig. 2, *A*), produced severe chlorosis and stunting (fig. 2, *C*). Likewise, 30 p. p. m., an injurious but not ordinarily fatal concentration, killed the plants where the sand had been added.

This increased severity of injury in sandy soil was further demonstrated by an experiment in which different percentages of sand were mixed with the clay loam. Sodium selenate at the rate of 20 p. p. m. of selenium by weight was added to all with thorough mixing. Where no sand was added the young plants after 3 weeks showed but an occasional trace of chlorosis; with one-fifth sand there was distinct whitening at the base of all the young leaves; with two-fifths sand chlorosis was much more severe and the plants were stunted; with three-fifths sand the chlorotic leaves were a deep rose pink at the base and extremely stunted, emergence of the second leaf being inhibited; and with four-fifths sand the plants turned yellow and died shortly after emerging from the soil. The occurrence of the pink color on the plants in the very sandy soil agreed with previous observations that plants in sand cultures frequently showed this coloration, while those in soil did so but rarely (*7*).

RETENTION OF SELENIUM BY SOIL AS SHOWN BY TOXICITY STUDIES WITH WHEAT

In interpreting the results of some experiments on possible effects of soil moisture on selenium toxicity, it was necessary to know whether the selenium of a sodium selenate solution becomes uniformly distributed throughout a mass of soil on the surface of which it is poured. To determine this, 600 cc of a solution of sodium selenate,

[6] The acidity determinations were made with the hydrogen electrode immersed in 1:1 and 1:2 suspensions of the soil.

[7] Analyses by J. B. Martin showed but 0.085 percent total sulphur and 0.002 percent water-soluble sulphur in this soil.

enough to supply 20 p. p. m. of selenium by weight of soil, was poured on the surface of 6,000 g of slightly moist soil in a 10-inch pot. The volume of solution was sufficient to penetrate to the bottom of the soil mass, which was approximately 5 inches deep. After standing for several days this soil was transferred in seven successive layers to as many small pots. Then all were brought to the same moisture content and sown with wheat. The relative amounts of selenium reaching each layer were shown by the different degrees of injury that appeared on the plants in the seven small pots. The condition of the plants 3 weeks after sowing, when the third leaf was emerging, was as follows:

Layer no. 1 (top layer of original soil mass)—plants stunted and yellow; too much injured to show white chlorosis on leaves.
Layer no. 2—chlorosis on all leaves; moderate stunting.
Layer no. 3—chlorosis first appearing at base of third leaf; slight stunting.
Layer no. 4—traces of chlorosis; no stunting.
Layers nos. 5–7—normal.

Apparently the selenium did not all penetrate with the water to the bottom of the original soil mass, there being no evidence of toxicity below the fourth layer.

To determine whether soil containing sand would be more penetrable to selenium, the experiment was repeated with 500 cc of a sodium selenate solution, supplying 40 p. p. m. of selenium by weight of soil, poured on 6,000 g of Keyport clay loam in each of four pots, two of which contained an admixture of 20 percent sand. The 500 cc volume of solution just penetrated to the bottom of the soil mass. The experiment was duplicated with the same quantity of selenate added in a volume of 1,000 cc, which made the bottom layers very wet and assured more than ample opportunity for thorough penetration. After standing 2 days the soil in each pot was layered as before into seven small pots. To determine the extent to which the water had penetrated the soil mass under the different conditions, these layers were sampled for moisture content. Then, after equalizing their moisture content, the relative selenium content of each layer was demonstrated by its toxicity to wheat seedlings. The data, together with observations on the condition of the seedlings at the age of 3 weeks, are reported in table 4.

The data in table 4 show that without the addition of sand the selenium did not penetrate below the third layer of the soil in sufficient amount to injure the seedlings. With the addition of sand, enough selenium to produce chlorosis penetrated to the fifth layer. The top layer always contained enough to produce fatal injury (fig. 4).

That the amount of selenium in the layers was not simply determined by the penetrability of the original soil mass to water was apparent from the lack of correlation between the degrees of injury and the moisture percentages of the layers. Distribution of the water was very uniform in the upper layers of both soils, especially where but 500 cc was used, yet the plants ranged from a dying condition in the top layer to normal or, in the sandy soil, nearly normal growth in the fourth. Furthermore, doubling the quantity of water in which the selenium was added, thereby mechanically aiding penetration and greatly increasing the amount of water that reached the lower soil layers, did not increase their toxicity.

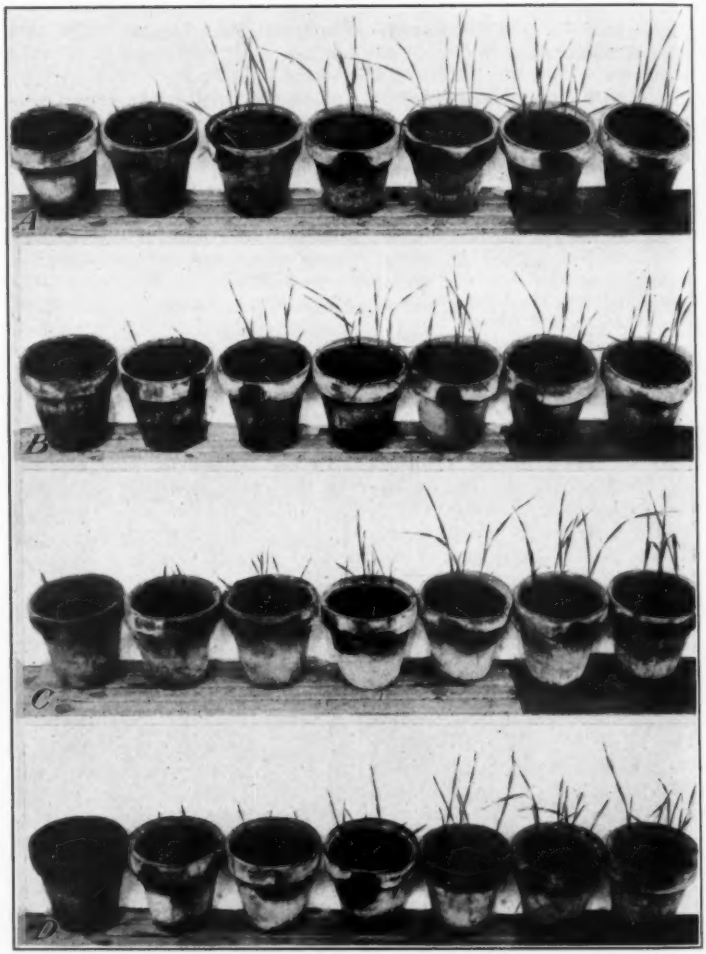

FIGURE 4.—Comparative growth of wheat seedlings in each of seven soil layers taken from top (left) to bottom (right) of four lots of soil (*A* to *D*) on the surface of each of which had been poured a solution of sodium selenate. The selenium had been added to the clay loam soil in volumes of 500 cc (series *A*) and 1,000 cc (series *B*), and to clay loam plus sand in volumes of 500 cc (series *C*) and 1,000 cc (series *D*).

TABLE 4.—*Retention of selenium by soils as shown by the comparative toxicity to wheat of the selenium contained in successive layers of a soil mass on the surface of which a solution of sodium selenate was poured*

Soil layer (numbered from top)	Keyport clay loam flooded with 0.56 g of selenate dissolved in—						Keyport clay loam plus 20 percent of sand flooded with 0.56 g of selenate dissolved in—				
	500 cc			1,000 cc			500 cc			1,000 cc	
	Condition of plants	Leaf chlorosis	Initial moisture	Condition of plants	Leaf chlorosis	Initial moisture	Condition of plants	Leaf chlorosis	Initial moisture	Condition of plants	Leaf chlorosis
			Pct.			*Pct.*			*Pct.*		
1	Dying		14.27	Dying		20.56	Dying		12.25	Dying	
2	Severely stunted.	+++	14.54	Severely stunted.	+++	18.72	Severely stunted.	+++	12.14	Severely stunted.	+++
3	Slightly stunted.	+	14.07	Slightly stunted.	+	18.19	do	+++	12.76	do	+++
4	Normal	0	14.10	Normal	0	17.99	Slightly stunted.	++	12.57	Slightly stunted.	++
5	do	0	13.65	do	0	17.25	Normal	+	12.43	Normal	+
6	do	0	13.14	do	0	16.76	do	0	11.45	do	0
7	do	0	11.75	do	0	16.49	do	0	10.91	do	0

Other evidence of retention of selenium by the soil was obtained on comparing the toxicity of a sodium selenate solution to wheat seedlings before and after filtering through Keyport clay loam. Two and a half liters of a highly toxic solution containing 200 p. p. m. of selenium was poured on the surface of 5,000 g of soil closely packed in a soil cylinder 30 cm high and 15 cm in diameter. The solution dripped through slowly, and five 100-cc portions were collected over an interval of 3 days. Each 100-cc portion was diluted to 1.5 l with water and poured on 7,000 g of quartz sand in a pot, which was then sown with wheat. None of the seedlings showed chlorosis or other symptoms of injury. Control pots received an equal volume of a solution containing 100 cc of an equivalent water extract of untreated soil (to provide the same quantities of sulphates and other soluble constituents) in addition to 100 cc of the selenate solution not filtered through the soil. The seedlings in these pots all became chlorotic. The absence of symptoms of toxicity where the selenium solution had been filtered through the soil was attributed to the disappearance of at least some of the selenium. It was concluded that when a solution of sodium selenate is poured on the surface of this soil the selenium does not all penetrate with the water in which it is dissolved but is at least partly retained in the upper layers.

COMPARATIVE ABSORPTION OF DIFFERENT FORMS OF SELENIUM

Elemental selenium is not readily if at all available to the wheat plant. When added to the Keyport clay loam in quantities up to 200 p. p. m. it produced no sign of toxicity and no trace of it could be found in plants tested by the codeine-sulphate method.

When compared on the basis of equal concentrations of selenium, sodium selenate was decidedly more toxic than sodium selenite. When 30 p. p. m. of selenium was added to the Keyport clay loam as sodium selenate, wheat plants were chlorotic, extremely stunted, and contained 1,000 p. p. m. of selenium, but when it was added as sodium selenite the plants were uninjured and contained but 10 p. p. m. of

selenium. In fact, the plants were not injured by concentrations as high as 70 p. p. m. of selenium added in the form of the selenite and analyses showed absorption of but 20 p. p. m. by weight of the tissues. A corresponding difference in absorption from the two salts was shown also by analyses of plants from other experiments. It is quite possible that the difference is attributable to rapid reduction of the selenite to elemental selenium in the soil.

EXHAUSTION OF SELENIUM FROM THE SOIL BY SUCCESSIVE CROPPINGS

Successive sowings of wheat in the same selenized soil were progressively less injured, indicating that sodium selenate was either reduced to a subtoxic concentration by the growth of the successive crops or changed to a less toxic form of selenium, possibly by the activity of microorganisms (*8*). Initial concentrations as high as 30 p. p. m. of selenium, which almost killed the plants of the first sowing, produced no visible effect on the plants of the fourth. In table 5 are recorded the relative degrees of chlorosis and stunting (indicated by number of plus signs) shown by four successive crops of wheat (five plants per pot) grown to maturity in 4,000 g of selenized soil. The soil remained without further treatment after the initial admixture of sodium selenate except for the addition of potassium nitrate when the plants began to show nitrogen deficiency.

TABLE 5.—*Progressively decreased toxicity of sodium selenate for successive crops of wheat in the same soil*

[Each crop consisted of 5 plants per pot]

Crop	Relative degrees of injury to wheat plants from the following concentrations of selenium as sodium selenate		
	5 p. p. m.	15 p. p. m.	30 p. p. m.
First	0	+++	++++
Second	0	++	+++
Third	0	0	+
Fourth	0	0	0

DISCUSSION

In the naturally seleniferous areas of the Middle West (*2*, *11*, *13*) the vegetation is very toxic to animals, yet shows no external symptoms of injury (*3*). In some of these areas surprisingly large accumulations of selenium in the plants are reported (*1*). The data presented in the present paper have shown that large quantities of selenium can be taken up by the plant before external symptoms of abnormality appear. Thus 380 p. p. m. was found in the leaves of plants grown in the Keyport clay loam to which had been added 10 p. p. m. of selenium (table 2), yet the plants showed no visible injury. Similarly, in the Pierre clay 325 p. p. m. was absorbed from 1 p. p. m. in the soil without visibly affecting the plants. This ability of the plant to accumulate selenium accounts for the toxicity to experimental animals of normal-appearing wheat grown with but 1 p. p. m. of selenium added as sodium selenate to the local clay loam (*10*).

Where excess sulphur is available still larger quantities of selenium can be taken up by the plants without injury. Those grown in Pierre clay to which was added 15 g of sulphur per 6,000 g of soil grew normally with 600 p. p. m. absorbed into their tissues from 20 p. p. m. of selenium in the soil, yet other plants on selenized soils with less sulphur were injured by lesser accumulations (table 3). Thus it is not possible to predict the selenium content of the tissues by their appearance, nor to establish any particular critical concentration within the plant which when exceeded will result in injury. Under the conditions of the present experiments some plants showed slight chlorosis with but a little over 300 p. p. m. of selenium in the tissues and others showed no chlorosis with twice this amount.

These experiments have suggested that whether or not the presence of a given amount of selenium results in visible injury depends on the amount of sulphur taken up to act as a protective agent by decreasing the chances of substitution of selenium for sulphur in molecules susceptible to such substitution. This explanation is based on the theory suggested previously to explain the selenium-sulphur antagonism (*7*). The theory assumes that because of their chemical similarity the plant is unable to distinguish between selenium and sulphur. While the total selenium plus sulphur absorbed by the plant would increase with that in the substratum, the proportionate amount of selenium in this total would be the same as that in the external medium. The relative number of selenium ions with reference to sulphur ions available within the plant would determine the proportionate number of "susceptible" molecules whose sulphur is replaced by selenium, and, consequently, the degree of injury to the plant. The excess selenium not so substituted might reasonably be supposed to occur in the plant as selenate (just as excess sulphur occurs as sulphate), incapable of harming the plant so long as excess sulphur sufficiently reduces the chance of substitution.

If these assumptions are correct, plants having excess sulphur available should absorb without injury quantities of selenium which would be fatal at lower sulphur levels. The data available indicate that they do. Moreover, the capacity for selenium absorption by a given crop should vary with the capacity for sulphur absorption and utilization characteristic of the species. That this generalization also obtains is suggested by the data in table 1, which show that the greatest absorption of selenium occurred in the two species of the Cruciferae, the least in representatives of the Gramineae, and that the legumes were intermediate. The three groups stand in this same order with respect to their sulphur requirements (*4*, *9*).

SUMMARY

Under the conditions of these experiments, the following factors have been found to affect the absorption and resulting toxicity to wheat of selenium added as sodium selenate to the soil: Available sulphur, soil type, percentage of sand, method of adding selenium, the form of selenium added, and growth of previous crops.

Of 17 different crops grown in Keyport clay loam with 5 p. p. m. selenium added as sodium selenate, the Cruciferae, broccoli and mustard, absorbed more selenium than any others, i. e., 1,180 and 1,240 p. p. m., respectively. It is suggested that the tendency of a crop to absorb selenium depends on its tendency to absorb sulphur.

acidifying effect was the complete control of the severe symptoms produced by 5 p. p. m. of selenium in the alkaline Pierre clay by the addition of an amount of sulphur (1 part in 600 parts of soil) which only slightly increased its acidity, that is, from pH 8.1 to 7.9 in one experiment and from 8.3 to 7.8 in another.[6] Moreover, rendering the Keyport clay loam alkaline by adding calcium carbonate (1 part in 500 parts soil) did not lessen the effectiveness of sulphur applications. Further evidence of the unimportance of acidity in selenium-sulphur antagonism was obtained incidentally in numerous experiments conducted with nutrient solutions, some of which are referred to in a previous publication (*7*).

To determine whether excess sulphur reduces absorption of naturally occurring selenium as well as that added as sodium selenate, plants were grown in the greenhouse in an untreated Pierre clay loam [7] containing 4 p. p. m. of naturally occurring selenium. Others were grown with elemental sulphur added at the rate of 1 part in 1,200 parts of this soil. The plants in the untreated soil were found to contain 450 p. p. m. of selenium, those in the sulphur-treated soil 15 p. p. m. Analyses of plants from other pots by M. J. Horn with the colorimetric codeine-sulphate method (*5*) indicated a similar reduction.

SELENIUM TOXICITY WITH DIFFERENT ADMIXTURES OF SAND TO SOIL

The addition of 20 percent of quartz sand to the local Keyport clay loam increased the toxicity of sodium selenate to the extent that 10 p. p. m. of selenium, an otherwise harmless concentration in this soil (fig. 2, *A*), produced severe chlorosis and stunting (fig. 2, *C*). Likewise, 30 p. p. m., an injurious but not ordinarily fatal concentration, killed the plants where the sand had been added.

This increased severity of injury in sandy soil was further demonstrated by an experiment in which different percentages of sand were mixed with the clay loam. Sodium selenate at the rate of 20 p. p. m. of selenium by weight was added to all with thorough mixing. Where no sand was added the young plants after 3 weeks showed but an occasional trace of chlorosis; with one-fifth sand there was distinct whitening at the base of all the young leaves; with two-fifths sand chlorosis was much more severe and the plants were stunted; with three-fifths sand the chlorotic leaves were a deep rose pink at the base and extremely stunted, emergence of the second leaf being inhibited; and with four-fifths sand the plants turned yellow and died shortly after emerging from the soil. The occurrence of the pink color on the plants in the very sandy soil agreed with previous observations that plants in sand cultures frequently showed this coloration, while those in soil did so but rarely (*7*).

RETENTION OF SELENIUM BY SOIL AS SHOWN BY TOXICITY STUDIES WITH WHEAT

In interpreting the results of some experiments on possible effects of soil moisture on selenium toxicity, it was necessary to know whether the selenium of a sodium selenate solution becomes uniformly distributed throughout a mass of soil on the surface of which it is poured. To determine this, 600 cc of a solution of sodium selenate,

[6] The acidity determinations were made with the hydrogen electrode immersed in 1:1 and 1:2 suspensions of the soil.

[7] Analyses by J. B. Martin showed but 0.085 percent total sulphur and 0.002 percent water-soluble sulphur in this soil.

enough to supply 20 p. p. m. of selenium by weight of soil, was poured on the surface of 6,000 g of slightly moist soil in a 10-inch pot. The volume of solution was sufficient to penetrate to the bottom of the soil mass, which was approximately 5 inches deep. After standing for several days this soil was transferred in seven successive layers to as many small pots. Then all were brought to the same moisture content and sown with wheat. The relative amounts of selenium reaching each layer were shown by the different degrees of injury that appeared on the plants in the seven small pots. The condition of the plants 3 weeks after sowing, when the third leaf was emerging, was as follows:

Layer no. 1 (top layer of original soil mass)—plants stunted and yellow; too much injured to show white chlorosis on leaves.
Layer no. 2—chlorosis on all leaves; moderate stunting.
Layer no. 3—chlorosis first appearing at base of third leaf; slight stunting.
Layer no. 4—traces of chlorosis; no stunting.
Layers nos. 5–7—normal.

Apparently the selenium did not all penetrate with the water to the bottom of the original soil mass, there being no evidence of toxicity below the fourth layer.

To determine whether soil containing sand would be more penetrable to selenium, the experiment was repeated with 500 cc of a sodium selenate solution, supplying 40 p. p. m. of selenium by weight of soil, poured on 6,000 g of Keyport clay loam in each of four pots, two of which contained an admixture of 20 percent sand. The 500 cc volume of solution just penetrated to the bottom of the soil mass. The experiment was duplicated with the same quantity of selenate added in a volume of 1,000 cc, which made the bottom layers very wet and assured more than ample opportunity for thorough penetration. After standing 2 days the soil in each pot was layered as before into seven small pots. To determine the extent to which the water had penetrated the soil mass under the different conditions, these layers were sampled for moisture content. Then, after equalizing their moisture content, the relative selenium content of each layer was demonstrated by its toxicity to wheat seedlings. The data, together with observations on the condition of the seedlings at the age of 3 weeks, are reported in table 4.

The data in table 4 show that without the addition of sand the selenium did not penetrate below the third layer of the soil in sufficient amount to injure the seedlings. With the addition of sand, enough selenium to produce chlorosis penetrated to the fifth layer. The top layer always contained enough to produce fatal injury (fig. 4).

That the amount of selenium in the layers was not simply determined by the penetrability of the original soil mass to water was apparent from the lack of correlation between the degrees of injury and the moisture percentages of the layers. Distribution of the water was very uniform in the upper layers of both soils, especially where but 500 cc was used, yet the plants ranged from a dying condition in the top layer to normal or, in the sandy soil, nearly normal growth in the fourth. Furthermore, doubling the quantity of water in which the selenium was added, thereby mechanically aiding penetration and greatly increasing the amount of water that reached the lower soil layers, did not increase their toxicity.

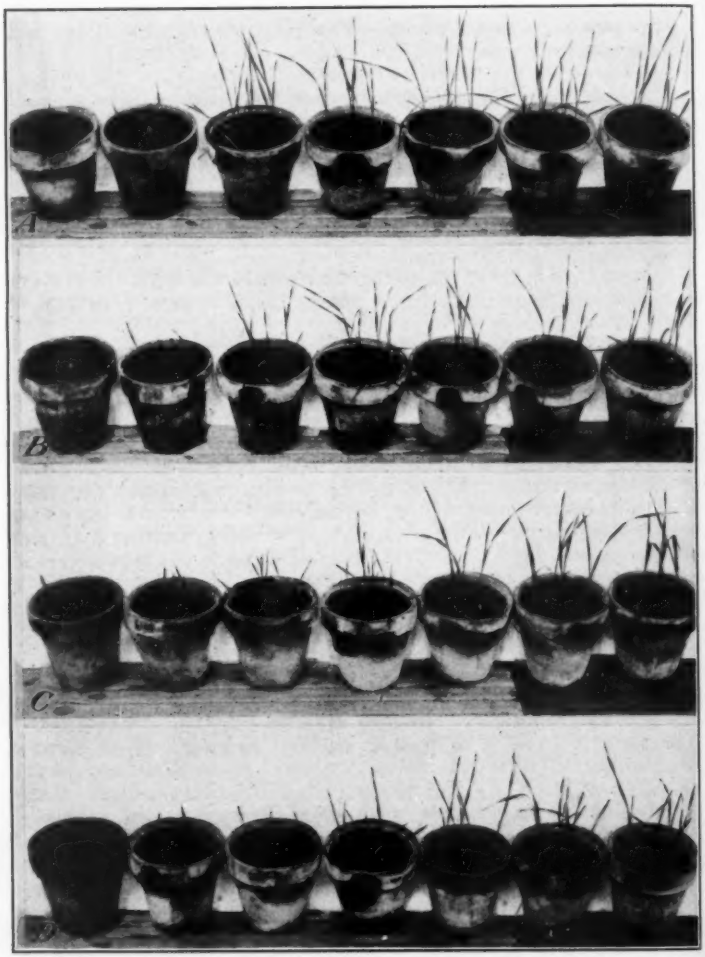

FIGURE 4.—Comparative growth of wheat seedlings in each of seven soil layers taken from top (left) to bottom (right) of four lots of soil (*A* to *D*) on the surface of each of which had been poured a solution of sodium selenate. The selenium had been added to the clay loam soil in volumes of 500 cc (series *A*) and 1,000 cc (series *B*), and to clay loam plus sand in volumes of 500 cc (series *C*) and 1,000 cc (series *D*).

TABLE 4.—*Retention of selenium by soils as shown by the comparative toxicity to wheat of the selenium contained in successive layers of a soil mass on the surface of which a solution of sodium selenate was poured*

Soil layer (numbered from top)	Keyport clay loam flooded with 0.56 g of selenate dissolved in—						Keyport clay loam plus 20 percent of sand flooded with 0.56 g of selenate dissolved in—				
	500 cc			1,000 cc			500 cc			1,000 cc	
	Condition of plants	Leaf chlorosis	Initial moisture	Condition of plants	Leaf chlorosis	Initial moisture	Condition of plants	Leaf chlorosis	Initial moisture	Condition of plants	Leaf chlorosis
			Pct.			*Pct.*			*Pct.*		
1	Dying		14.27	Dying		20.56	Dying		12.25	Dying	
2	Severely stunted.	+++	14.54	Severely stunted.	+++	18.72	Severely stunted.	+++	12.14	Severely stunted.	+++
3	Slightly stunted.	+	14.07	Slightly stunted.	+	18.19	...do...	+++	12.76	...do...	+++
4	Normal	0	14.10	Normal	0	17.99	Slightly stunted.	++	12.57	Slightly stunted.	++
5	...do...	0	13.65	...do...	0	17.25	Normal	+	12.43	Normal	+
6	...do...	0	13.14	...do...	0	16.76	...do...	0	11.45	...do...	0
7	...do...	0	11.75	...do...	0	16.49	...do...	0	10.91	...do...	0

Other evidence of retention of selenium by the soil was obtained on comparing the toxicity of a sodium selenate solution to wheat seedlings before and after filtering through Keyport clay loam. Two and a half liters of a highly toxic solution containing 200 p. p. m. of selenium was poured on the surface of 5,000 g of soil closely packed in a soil cylinder 30 cm high and 15 cm in diameter. The solution dripped through slowly, and five 100-cc portions were collected over an interval of 3 days. Each 100-cc portion was diluted to 1.5 l with water and poured on 7,000 g of quartz sand in a pot, which was then sown with wheat. None of the seedlings showed chlorosis or other symptoms of injury. Control pots received an equal volume of a solution containing 100 cc of an equivalent water extract of untreated soil (to provide the same quantities of sulphates and other soluble constituents) in addition to 100 cc of the selenate solution not filtered through the soil. The seedlings in these pots all became chlorotic. The absence of symptoms of toxicity where the selenium solution had been filtered through the soil was attributed to the disappearance of at least some of the selenium. It was concluded that when a solution of sodium selenate is poured on the surface of this soil the selenium does not all penetrate with the water in which it is dissolved but is at least partly retained in the upper layers.

COMPARATIVE ABSORPTION OF DIFFERENT FORMS OF SELENIUM

Elemental selenium is not readily if at all available to the wheat plant. When added to the Keyport clay loam in quantities up to 200 p. p. m. it produced no sign of toxicity and no trace of it could be found in plants tested by the codeine-sulphate method.

When compared on the basis of equal concentrations of selenium, sodium selenate was decidedly more toxic than sodium selenite. When 30 p. p. m. of selenium was added to the Keyport clay loam as sodium selenate, wheat plants were chlorotic, extremely stunted, and contained 1,000 p. p. m. of selenium, but when it was added as sodium selenite the plants were uninjured and contained but 10 p. p. m. of

selenium. In fact, the plants were not injured by concentrations as high as 70 p. p. m. of selenium added in the form of the selenite and analyses showed absorption of but 20 p. p. m. by weight of the tissues. A corresponding difference in absorption from the two salts was shown also by analyses of plants from other experiments. It is quite possible that the difference is attributable to rapid reduction of the selenite to elemental selenium in the soil.

EXHAUSTION OF SELENIUM FROM THE SOIL BY SUCCESSIVE CROPPINGS

Successive sowings of wheat in the same selenized soil were progressively less injured, indicating that sodium selenate was either reduced to a subtoxic concentration by the growth of the successive crops or changed to a less toxic form of selenium, possibly by the activity of microorganisms (*8*). Initial concentrations as high as 30 p. p. m. of selenium, which almost killed the plants of the first sowing, produced no visible effect on the plants of the fourth. In table 5 are recorded the relative degrees of chlorosis and stunting (indicated by number of plus signs) shown by four successive crops of wheat (five plants per pot) grown to maturity in 4,000 g of selenized soil. The soil remained without further treatment after the initial admixture of sodium selenate except for the addition of potassium nitrate when the plants began to show nitrogen deficiency.

TABLE 5.—*Progressively decreased toxicity of sodium selenate for successive crops of wheat in the same soil*

[Each crop consisted of 5 plants per pot]

Crop	Relative degrees of injury to wheat plants from the following concentrations of selenium as sodium selenate		
	5 p. p. m.	15 p. p. m.	30 p. p. m.
First	0	+++	++++
Second	0	++	+++
Third	0	0	+
Fourth	0	0	0

DISCUSSION

In the naturally seleniferous areas of the Middle West (*2, 11, 13*) the vegetation is very toxic to animals, yet shows no external symptoms of injury (*3*). In some of these areas surprisingly large accumulations of selenium in the plants are reported (*1*). The data presented in the present paper have shown that large quantities of selenium can be taken up by the plant before external symptoms of abnormality appear. Thus 380 p. p. m. was found in the leaves of plants grown in the Keyport clay loam to which had been added 10 p. p. m. of selenium (table 2), yet the plants showed no visible injury. Similarly, in the Pierre clay 325 p. p. m. was absorbed from 1 p. p. m. in the soil without visibly affecting the plants. This ability of the plant to accumulate selenium accounts for the toxicity to experimental animals of normal-appearing wheat grown with but 1 p. p. m. of selenium added as sodium selenate to the local clay loam (*10*).

Where excess sulphur is available still larger quantities of selenium can be taken up by the plants without injury. Those grown in Pierre clay to which was added 15 g of sulphur per 6,000 g of soil grew normally with 600 p. p. m. absorbed into their tissues from 20 p. p. m. of selenium in the soil, yet other plants on selenized soils with less sulphur were injured by lesser accumulations (table 3). Thus it is not possible to predict the selenium content of the tissues by their appearance, nor to establish any particular critical concentration within the plant which when exceeded will result in injury. Under the conditions of the present experiments some plants showed slight chlorosis with but a little over 300 p. p. m. of selenium in the tissues and others showed no chlorosis with twice this amount.

These experiments have suggested that whether or not the presence of a given amount of selenium results in visible injury depends on the amount of sulphur taken up to act as a protective agent by decreasing the chances of substitution of selenium for sulphur in molecules susceptible to such substitution. This explanation is based on the theory suggested previously to explain the selenium-sulphur antagonism (*7*). The theory assumes that because of their chemical similarity the plant is unable to distinguish between selenium and sulphur. While the total selenium plus sulphur absorbed by the plant would increase with that in the substratum, the proportionate amount of selenium in this total would be the same as that in the external medium. The relative number of selenium ions with reference to sulphur ions available within the plant would determine the proportionate number of "susceptible" molecules whose sulphur is replaced by selenium, and, consequently, the degree of injury to the plant. The excess selenium not so substituted might reasonably be supposed to occur in the plant as selenate (just as excess sulphur occurs as sulphate), incapable of harming the plant so long as excess sulphur sufficiently reduces the chance of substitution.

If these assumptions are correct, plants having excess sulphur available should absorb without injury quantities of selenium which would be fatal at lower sulphur levels. The data available indicate that they do. Moreover, the capacity for selenium absorption by a given crop should vary with the capacity for sulphur absorption and utilization characteristic of the species. That this generalization also obtains is suggested by the data in table 1, which show that the greatest absorption of selenium occurred in the two species of the Cruciferae, the least in representatives of the Gramineae, and that the legumes were intermediate. The three groups stand in this same order with respect to their sulphur requirements (*4*, *9*).

SUMMARY

Under the conditions of these experiments, the following factors have been found to affect the absorption and resulting toxicity to wheat of selenium added as sodium selenate to the soil: Available sulphur, soil type, percentage of sand, method of adding selenium, the form of selenium added, and growth of previous crops.

Of 17 different crops grown in Keyport clay loam with 5 p. p. m. selenium added as sodium selenate, the Cruciferae, broccoli and mustard, absorbed more selenium than any others, i. e., 1,180 and 1,240 p. p. m., respectively. It is suggested that the tendency of a crop to absorb selenium depends on its tendency to absorb sulphur.

Sodium selenate is more easily absorbed by wheat from Pierre clay than from Keyport clay loam. The greatest accumulation was 1,350 p. p. m., found in plants fatally injured by 20 p. p. m. of selenium as sodium selenate added to Pierre clay.

Elemental sulphur applications reduce the absorption by wheat of the naturally occurring selenium in the soil, as well as of that added as sodium selenate. Gypsum is similarly effective.

The addition of quartz sand to Keyport clay loam increases the toxicity of sodium selenate in proportion to the percentage of sand in the mixture.

Sodium selenate is not easily leached from Keyport clay loam, being at least partially retained in the upper layers when a solution containing it is poured on the surface. Solutions originally toxic are nontoxic after being filtered through this soil. The presence of sand increases penetrability.

Elemental selenium is apparently unavailable and nontoxic to wheat plants, at least in quantities up to 200 p. p. m. in Keyport clay loam.

The selenium in sodium selenate is more available and more toxic to wheat than that in sodium selenite, the comparison being made on the basis of equal concentrations of selenium.

Sodium selenate was either changed to a less toxic form of selenium or reduced to a subtoxic concentration by the growth of successive crops of wheat.

LITERATURE CITED

(1) Beath, O. A., Draize, J. H., Eppson, H. F., Gilbert, C. S., and McCreary, O. C.
1934. certain poisonous plants of wyoming activated by selenium and their association with respect to soil types. Jour. Amer. Pharm. Assoc. 23: 94–97.

(2) Byers, H. G.
1934. selenium, vanadium, chromium, and arsenic in one soil. Indus. and Engin. Chem., News Ed. 12: 122.

(3) Franke, K. W., Rice, T. D., Johnson, A. G., and Schoening, H. W.
1934. report on a preliminary field survey of the so-called "alkali disease" of livestock. U. S. Dept. Agr. Circ. 320, 10 pp., illus.

(4) Hart, E. B., and Tottingham, W. E.
1915. relation of sulphur compounds to plant nutrition. Jour. Agr. Research 5: 233–250, illus.

(5) Horn, M. J.
1934. qualitative method for selenium in organic compounds. Indus. and Engin. Chem., Analyt. Ed. 6: 34–35.

(6) Hurd-Karrer, A. M.
1933. inhibition of selenium injury to wheat plants by sulphur. Science (n. s.) 78: 560.

(7) ———
1934. selenium injury to wheat plants and its inhibition by sulphur. Jour. Agr. Research 49: 343–357, illus.

(8) Levine, V. E.
1925. the reducing properties of micro-organisms with special reference to selenium compounds. Jour. Bact. 10: 217–262, illus.

(9) Miller, H. G.
1919. relation of sulphates to plant growth and composition. Jour. Agr. Research 17: 87–102, illus.

(10) Nelson, E. M., Hurd-Karrer, A. M., and Robinson, W. O.
1933. selenium as an insecticide. Science (n. s.) 78: 124.

(11) Robinson, W. O., Dudley, H. C., Williams, K. T., and Byers, H. G.
1934. determination of selenium and arsenic by distillation in pyrites, shales, soils, and agricultural products. Indus. and Engin. Chem., Analyt. Ed. 6: 274–276, illus.
(12) ——— and Holmes, R. S.
1924. the chemical composition of soil colloids. U. S. Dept. Agr. Bull. 1311, 42 pp.
(13) Williams, K. T., and Byers, H. G.
1934. occurrence of selenium in pyrites. Indus. and Engin. Chem., Analyt. Ed. 6: 296–297.

DORMANCY AND MATURITY OF COTTONSEED [1]

By D. M. SIMPSON [2]

Associate agronomist, Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

In studying the moisture content and germination of cottonseed during the period of boll opening at the United States Acclimatization Field Station, near Charleston, S. C., it was found that germination tests made on the seed immediately after they were harvested were unreliable. The fresh seed germinated very slowly, and many seed, though apparently sound, failed to germinate even after being in the germination chambers for 24 days. However, when fresh seed was thoroughly air-dried and stored for a few weeks, better germination was obtained.

DORMANCY OF FRESH SEED

In 1932, seed samples of several cotton varieties were studied to determine the moisture content and the percentage germination immediately after harvesting and after drying and storing for 1 month. Data in table 1 show the degree of dormancy of fresh seed of bolls open from 1 to 10 days of the upland varieties Tidewater, Cleveland, and Foster, and of the Seabrook strain of sea island.

The fresh seed of all the upland varieties from bolls open 1 to 5 days germinated very slowly, and a considerable percentage of sound or dormant seed remained ungerminated after being in the germination chambers for 24 days; whereas complete germinations usually are obtained from normal dry seed in from 5 to 7 days. While more rapid germination and higher total percentages of germination were obtained from fresh seed that had remained in the field more than 5 days, the rate of germination was not so rapid as that of seed which had been dried and stored, nor was the seed entirely free from dormancy. In practically every case, the germination percentage of the seed which was dried and stored for 1 month was higher than that of fresh seed of the same sample. In the case of seed from bolls of the upland varieties open only 1 and 2 days, drying and storing increased the germination percentages by an average of 56.4 percent. There was no appreciable difference in dormancy of fresh seed among the several upland varieties.

[1] Received for publication Sept. 25, 1934; issued May 1935.

[2] The writer is indebted to B. M. Stone, formerly assistant scientific aid, Division of Cotton and Other Fiber Crops and Diseases, for the collection of many of the data presented in this paper.

TABLE 1.—*Dormancy of cottonseed during the period of boll opening at the United States Acclimatization Field Station, James Island, S. C., 1932*

TIDEWATER (TAGGED SEPT. 7)

Bolls picked	Percentage of moisture in seed	Percentage of seed germinated after designated number of days in germinator																					Percentage of sound but ungerminated seed	Percentage of seed germinated after being dried and stored about 1 month, and after designated number of days in germinator		
		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total		5	7	Total
Sept. 7	52.0									13			6				11		2				32	30	84	7	91
8	43.0						21				10					11		1			3		46	27	90	3	93
9	34.7				17			14			4				10		4		2				51	27	90	1	91
10	31.2						43			5						5							53	7	85	2	87
11	13.0					59			12			3											74	2	93	3	96
12	12.1				60			12			3			1									76	0	93	3	96
13	11.2					72				9													81	3	95	2	97
14	27.2				79					8													87	3	85	5	90
15	34.0				63				6		3					1							73	12	92	1	93
16	23.3		42	18		16		3		1													80	0	85	2	87

CLEVELAND (TAGGED SEPT. 7)

Sept. 7	48.7									13			6				11		2				32	30	54	19	73
8	38.9						3				9					5		3			7		27	59	75	12	87
9	29.7				8			13			8				8		3		2				42	39	59	29	88
10	17.3					17			7						11								35	17	41	44	85
11	15.9					10		18				10					8						46	21	64	20	84
12	13.3				12			15			24		10										61	13	55	39	94
13	12.7					14					27		8		7								56	26	73	14	87
14	27.5				21					41		4			1								67	17	90	7	97
15	38.7				15				18							2							35	42	70	17	87
16	22.8		5	14		13		8		9													49	15	75	6	81

FOSTER (TAGGED SEPT. 7)

Sept. 7	50.9									5			4				26		11				46	41	95	0	95
8	41.0						1				2						20		12			7	42	35	94	1	95
9	28.5				10			13			7				10		2		1				43	22	78	16	94
10	16.0						56			6						6							68	6	88	8	96
11	12.7					24			23				10				1						58	11	54	42	96
12	10.6				27			27			10												64	8	63	30	93
13	11.3					30					39		5										74	12	94	3	97
14	28.3				33					49		2											84	4	76	20	96
15	35.9				25				40		4					4							73	8	83	11	94
16	21.6		9	8		35		13		4													69	8	77	10	87

TIDEWATER (TAGGED SEPT. 20)

Sept. 20	54.1					19					4							6				3	32	42	[1] 88	9	97
21	51.7						6			9			6				4		7				32	50	[1] 96	1	97
22	45.6			10		7			15							3							35	32	[1] 72	17	89
23	38.2		14			19				14					5		3		3				58	22	[1] 92	4	96
24	31.0			43			16		7		1												67	4	[1] 84	7	91
25	24.9			34			25			13						4							76	0	[1] 84	6	90
26	27.0				49		7		4														60	3	[1] 79	2	81
27	28.6			45		14		5															64	0	[1] 64	2	66
28	22.5		34		19		5			2													60	0	[1] 80	12	92
29	[2]	42		24		6																	72	2	[1] 76	2	78

[1] After 4 days in germinator.
[2] Moisture content of seed was not determined.

TABLE 1.—*Dormancy of cottonseed during the period of boll opening of the United States Acclimatization Fied Station, James Island, S. C., 1932*—Continued

CLEVELAND (TAGGED SEPT. 20)

Bolls picked	Percentage of moisture in seed	Percentage of seed germinated after designated number of days in germinator																					Percentage of sound but ungerminated seed	Percentage of seed germinated after being dried and stored about 1 month, and after designated number of days in germinator		
		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total		5	7	Total
Sept. 20	48.8					12					8							6				4	30	53	[1] 84	9	93
21	47.9						12			10				9			13		6				50	42	[1] 69	20	89
22	46.3			9		5			11							6							31	53	[1] 72	18	90
23	34.0		17			21				2					8		6		2				56	27	[1] 65	32	97
24	30.1			14			28		1		6			9									58	22	[1] 67	26	93
25	26.7			16			21			23						3							63	15	[1] 84	5	89
26	28.7				29		8		8														45	0	[1] 65	8	73
27	31.1			16		26		14			3												59	0	[1] 57	20	77
28	27.1		17		28		8			2													55	0	[1] 66	10	76
29	[2]	3		37		22			9														71	9	[1] 48	25	73

FOSTER (TAGGED SEPT. 20)

Sept. 20	50.1										7							23				2	32	28	[1] 88	9	97
21	47.4						6			9				21			12		5				53	30	[1] 96	1	97
22	36.6					3		1			4							7					15	14	[1] 72	17	89
23	30.0		6			20			15						28		5		2				76	10	[1] 92	4	96
24	23.3			3			33		19		10			4									69	8	[1] 84	7	91
25	20.9			24			41			13			6			9							93	0	[1] 84	6	90
26	23.8				35		33		11						1								80	1	[1] 79	2	81
27	31.5			36		19		21			12												88	0	[1] 64	2	66
28	25.2		17		17		17			13													64	0	[1] 80	12	92
29	[2]	13		37		25			11														86	6	[1] 76	2	78

TIDEWATER (TAGGED OCT. 5)

Oct. 5	53.9				3			1						1									5	50	79	1	80
6	53.1			2			7							10		5							24	53	82	6	88
7	52.2		2			5			2				4		3								16	73	77	6	83
8	48.2			3			7					6		5									21	67	87	1	88
9	33.0			3		6				9		5											23	61	87	5	92
10	37.8				19				4		2												25	56	86	3	89
11	24.5		33		11			9		3													56	14	81	9	90
12	15.8	10				57	3		7														77	11	85	9	94
13	11.3	31			47	7																	85	7	93	4	97
14	13.7	10		18		38		12															78	12	78	6	84

SEA ISLAND (TAGGED OCT. 5)

Oct. 5	48.4				85			7															92	0	[1] 96	0	96
6	48.2			70			24								1								95	0	[1] 97	0	97
7	49.0		58			31								4									93	0	[1] 96	0	96
8	41.2			99				2					2										91	0	[1] 94	1	95
9	29.4			89			8																97	0	[1] 96	0	96
10	20.2	89				1																	90	0	[1] 97	1	98
11	17.1			87		3																	90	0	[1] 91	6	97
12	13.9	95																					95	0	[1] 92	0	92
13	12.3	89				2																	91	0	[1] 92	0	92
14	13.8	96		2																			98	0	[1] 97	0	97

[1] After 4 days in germinator.
[2] Moisture content of seed was not determined.

From the differences in germination of fresh and dried seed, it is evident that the percentage of sound seed remaining in the germinator after 24 days did not represent the total percentage of dormant seed. The results indicated that many seed which rotted under the conditions of high temperature and moisture in the germinator would have germinated if they had been dried and stored for a short period.

The total germination percentages of both fresh and dried seed were affected by the length of time during which the seed had been exposed previously in the field, but some degree of dormancy was evident even in seed from bolls harvested 10 days after opening began. When the seed was dried and stored, higher total germinations usually were obtained from the seed which was harvested when the bolls were just beginning to open and before any field deterioration could take place than from bolls exposed for a longer period in the field. This was particularly evident in samples from bolls opening during periods of wet weather, as from September 20 to 29, rain being recorded on 6 days of this period.[3]

The behavior of fresh sea-island seed as regards dormancy was in striking contrast to that of the upland varieties. The comparison between the Tidewater and sea island given in the latter part of table 1 shows that the fresh seed of the sea island required only a few days more to germinate than the dried seed and that the total germination percentages were only slightly lower for fresh seed than for seed which was dried and stored for 1 month. Of the seed from sea-island bolls harvested on the first day after opening began, 85 percent germinated in 7 days and 92 percent in 10 days. Of the Tidewater seed harvested at the same time only 5 percent germinated in 24 days, but in the sample that was dried and stored 80 percent germinated in 7 days.

Since dormancy of fresh seed may be eliminated by drying and storing for a short period, it is of interest to know whether drying alone will give equally good results. To obtain information on this point, 20 bolls of Tidewater cotton, one-fourth inch open at the tips, were picked on October 18 and divided into 3 samples. The seeds were removed from sample 1 and placed in the germinator immediately. Samples 2 and 3 were thoroughly dried, and on October 24 the seeds of sample 2 were placed in the germinator. Sample 3, after being dried, was placed in storage and kept there until November 18, when it was placed in the germinator. The germination percentages for these 3 samples were 12 for the fresh undried seed, 75 for the dried unstored seed, and 84 for the dried seed stored for 30 days. The fresh undried seed continued to germinate for 21 days; 59 percent of the dried unstored seed germinated in 7 days and germination was complete in 12 days. Seventy-two percent of the seed of sample 3, which was dried and stored, germinated in 5 days and 84 percent in 7 days. These data indicate that, while a part of the dormancy may be removed by drying alone, further improvement in the germination of the seed is obtained by short storage after drying.

SEED MATURITY

Experiments had indicated that seed from bolls just beginning to open, if properly dried and stored, would give high germination percentages and that the failure of these seed to germinate immedi-

[3] See table 1 of the following publication: SIMPSON, D. M., and STONE, B. M. VIABILITY OF COTTONSEED AS AFFECTED BY FIELD CONDITIONS. Jour. Agr. Research 50:435-447. 1935.

ately after harvesting was due to dormancy and not to immaturity of the seed.

In order to determine at what age in the development of the boll the seed becomes germinable, an experiment was conducted in 1932 in which seed from bolls of known age was used. Samples of bolls of Tidewater cotton were collected 21 to 56 days after flowering. The seed cotton was removed from these bolls at the time of harvesting and sun-dried to remove excess moisture. The samples were then stored for approximately 1 month before the germination tests were made. Seed from bolls 21 to 42 days old failed to germinate. Sixty-eight percent of seed from bolls 46 days old germinated, and higher germination percentages were obtained as the percentage of open bolls increased. Bolls began opening about 48 days after flowering and all bolls were open 51 days after flowering. Germination percentages at 52, 54, and 56 days after flowering were 86, 81, and 91, respectively.

Further information on seed maturity was collected in 1933, the data in table 2 being obtained on four varieties of upland cotton at three periods during the season. Ten percent of the seed of the Foster variety from flowers tagged on June 15 germinated at 40 days from fertilization, while seed of other varieties failed to germinate at 40 days. A few seed in all varieties germinated at 42 days from fertilization, and normal germination percentages of seed of all varieties were obtained 48 to 50 days after flowering.

TABLE 2.—*Germination of seed from bolls of four varieties of cotton harvested from 40 to 50 days after flowering, James Island, S. C., 1933*

Days after flowering (number)	Percentage germination of seed				Remarks
	Tidewater	Coker Wilds	Foster	Cleveland	
FLOWERS TAGGED JUNE 15					
40	0	0	10	0	
42	11	7	12	16	
44	28	24	47	27	2 bolls of Foster open.
46	33	9	37	90	1 Tidewater, 1 Foster, and all Cleveland open.
48	65	80	90	83	2 Tidewater, 1 Coker Wilds, all Foster and Cleveland open.
50	95	79	68	89	All bolls open.
FLOWERS TAGGED JUNE 22					
40	3	12	25	13	
42	36	55	68	71	1 Tidewater, 2 Foster, and 4 Cleveland open.
44	83	84	87	75	2 Tidewater, 3 Coker Wilds, and all Cleveland open.
46	87	74	97	77	3 Tidewater, 3 Coker Wilds, 6 Foster, and all Cleveland open.
48	71	76	86	87	4 Tidewater and all others open.
50	67	95	93	94	All bolls open.
FLOWERS TAGGED JULY 7					
40	68	42	74	36	
42	45	39	66	60	
44	67	64	74	68	
46	57	.....	57	76	
48	74	.....	.....	.....	

Bolls from flowers tagged on June 22 and July 7 were progressively earlier in maturing seed. This would be expected, as the warmer weather of midsummer hastened the maturity of the bolls. Some irregularities in individual germination percentages and in the final total are due to sampling and to field deterioration of seed in the open bolls.

SUMMARY

Experiments conducted at James Island, near Charleston, S. C., indicate that freshly opened cotton bolls contain a considerable percentage of dormant seed. This dormancy may be eliminated by drying and storing the seed for a short period. There was no appreciable difference in dormancy of fresh seed among several upland varieties; the sea-island strain tested showed practically no dormancy.

Studies of seed maturity indicated that cottonseed reaches maturity shortly before the bolls begin to open; at James Island, S. C., this period is from 40 to 50 days after flowering.

VIABILITY OF COTTONSEED AS AFFECTED BY FIELD CONDITIONS[1]

By D. M. SIMPSON, *associate agronomist*, and B. M. STONE, formerly *assistant scientific aid, Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture*[2]

INTRODUCTION

Differences in the viability of cottonseed produced in different seasons have been recognized, and agricultural agencies frequently find it necessary to issue precautionary warnings to farmers regarding the low viability of planting seed in certain sections of the Cotton Belt. Although the low viability of the planting seed is generally attributed to seasonal conditions, little information is available as to the causes of seed deterioration or the relation of seasonal conditions to seed viability.

Experiments conducted at the United States Acclimatization Field Station, James Island, S. C., in 1931, 1932, and 1933 indicate definite relations between seed viability and the weather conditions prevailing while the seed cotton is exposed in the field. The climate at James Island is characterized by high humidity and frequent rains during the harvesting season. Such conditions are unfavorable for the production of seed of high germination, but they provide an opportunity for the study of the causes of deterioration which would not be afforded in a section where conditions for the production of good seed more uniformly prevail.

MOISTURE CONTENT AND GERMINATION OF SEED DURING BOLL-OPENING PERIOD

Weather conditions (table 1) prevailing in the coastal section of the Southeastern States during the cotton-picking season necessitate the harvesting of the cotton as rapidly as is practicable after boll opening begins. The cotton is picked at about 10-day intervals if weather conditions permit. While picking at such short intervals prevents undue exposure of cotton in the fields and protects the quality and grade of the fiber, many bolls containing a high percentage of moisture are usually included in the harvested cotton.

Examination of seed cotton as brought in from the field showed that an appreciable amount of the excess moisture was due to the picking of partially opened bolls. Because of this it was desirable to determine the amount of moisture present in the bolls during the opening process and the rate of drying and the viability of the seed of the partially opened bolls.[3]

Experiments were begun in 1931 to determine the moisture content of the seed cotton and seed and the germination of the seed during

[1] Received for publication Sept. 25, 1934; issued May 1935.

[2] The writers are indebted to E. H. Toole, physiologist, Division of Seed Investigations, Bureau of Plant Industry, for suggestions in planning these experiments and for instruction in the technic of seed germination.

[3] The extraction of moisture from the various samples of material for determinations of moisture percentages was accomplished by weighing the samples before drying in an electric oven for approximately 24 hours at a constant temperature of 100° C. The samples were then placed in a desiccator to cool before making the final weighing.

the period of boll opening. Two hundred bolls of the Tidewater variety were tagged just as they were beginning to open at the tip. The bolls were tagged on September 15, and, beginning on that date, two 10-boll samples were picked at random each week day to and including September 25. The samples in the first series were used to determine the moisture content of the seed cotton, while those in the other series were ginned and determinations were made of the moisture content and germination percentage of the seed.

TABLE 1.—*Maximum and minimum temperatures, relative humidity, and rainfall, from Aug. 1 to Oct. 19, 1931, 1932, and 1933, at the United States Acclimatization Field Station, James Island, S. C.*

Date	1931				1932						1933					
	Temperature		Relative humidity at 8 a. m.	Rainfall (24-hour period) recorded at 8 a. m.	Temperature		Relative humidity at—			Rainfall (24-hour period) recorded at 8 a. m.	Temperature		Relative humidity at—			Rainfall (24-hour period) recorded at 8 a. m.
	Maximum	Minimum			Maximum	Minimum	8 a. m.	1 p. m.	5 p. m.		Maximum	Minimum	8 a. m.	1 p. m.	5 p. m.	
	° F.	° F.	Pct.	Inches	° F.	° F.	Pct.	Pct.	Pct.	Inches	° F.	° F.	Pct.	Pct.	Pct.	Inches
Aug. 1	87.5	70.5	76	.....	85.0	77.0	82	.....	.....	.....	89.0	74.0	75	.....	.....	.....
2	89.0	76.5	.....	.....	85.5	77.0	74	.....	.....	.....	89.0	72.5	80	.....	.....	.....
3	89.5	78.0	76	.....	89.0	78.0	76	.....	.....	.....	87.0	77.0	80	.....	73	.....
4	90.5	76.0	80	.....	88.0	80.0	76	.....	.....	.....	88.5	74.0	78	77	.....	0.50
5	90.0	76.0	77	.....	85.0	72.0	93	.....	.....	1.63	88.0	70.0	85	.....	.....	.44
6	89.5	68.5	69	.....	82.0	73.0	86	.....	.....	1.40	88.0	71.0	80	72	.....	.....
7	87.0	71.5	91	.....	87.0	77.0	84	.....	.....	.07	87.0	72.0	88	64	74	.....
8	89.0	71.0	91	0.45	87.0	74.0	87	.....	.....	.....	87.0	72.0	83	73	76	.....
9	89.5	73.5	.....	.....	87.0	73.0	85	.....	.....	.09	89.0	70.5	85	63	63	.....
10	88.0	76.0	83	.61	86.5	73.0	87	83	.....	.....	90.0	74.5	81	70	.....	.....
11	82.5	72.5	.....	.....	90.5	75.0	80	68	70	.01	92.0	76.0	76	72	70	.01
12	80.0	63.0	95	1.33	93.0	75.0	80	65	78	.....	90.0	75.5	82	.....	77	.....
13	85.5	66.0	85	.09	90.0	73.0	85	69	74	.03	89.0	70.0	87	.....	77	1.74
14	81.0	66.0	93	.53	83.0	75.0	81	48	.....	.10	90.5	75.0	79	57	67	.01
15	84.0	70.0	87	.80	84.0	70.0	73	66	72	.....	90.0	70.0	78	57	81	.....
16	85.5	73.5	.....	.....	87.0	69.5	79	.....	67	.....	86.0	72.5	93	77	83	.28
17	89.5	70.5	75	.....	86.0	70.0	70	61	61	.....	83.5	72.5	98	80	83	.14
18	86.0	69.5	75	.....	87.0	69.0	69	60	.....	.....	87.5	73.0	91	62	79	.35
19	86.5	73.0	84	.....	82.0	72.0	95	85	85	.35	77.5	70.5	95	93	.....	.38
20	89.0	74.5	76	.....	77.5	73.0	98	89	.....	.81	77.5	70.0	98	.....	.....	.65
21	87.5	70.0	79	.....	80.0	70.5	98	81	84	4.00	77.0	70.0	98	.....	96	.55
22	85.0	69.0	82	.....	79.0	70.5	91	87	83	.08	83.0	71.5	89	75	75	.26
23	77.5	58.0	.....	.....	82.5	71.5	85	76	.....	.04	87.5	69.0	78	67	76	.....
24	85.0	56.0	81	.....	82.5	70.5	93	77	77	.....	87.0	74.5	79	75	74	.....
25	87.0	61.0	71	.....	82.0	70.0	84	79	81	1.32	88.5	73.5	88	73	80	.....
26	85.5	70.0	67	.....	84.5	71.0	83	68	81	.....	90.0	75.0	84	77	.....	.....
27	86.5	68.5	77	.....	85.0	72.0	81	69	73	.....	92.0	78.0	88	.....	.....	.23
28	95.0	66.5	85	.85	88.0	70.0	91	66	74	.....	91.0	74.0	78	69	72	.01
29	89.5	73.0	79	.....	89.5	71.5	89	66	68	.....	92.5	78.0	80	67	78	.....
30	86.0	70.0	.....	.....	89.5	72.5	91	61	84	.....	82.0	72.5	98	.....	85	.17
31	85.0	66.0	87	.75	88.5	73.5	88	67	82	.....	84.0	71.0	91	76	.....	.30
Sept. 1	86.0	67.0	87	.....	89.0	73.5	84	67	80	.....	85.5	72.0	89	73	93	1.15
2	85.0	68.0	75	.....	92.0	73.0	91	65	61	.....	85.0	72.5	85	.....	.....	.01
3	88.0	73.0	85	.89	86.0	76.0	73	69	.....	.....	87.0	81.0	80	.....	.....	.....
4	88.5	67.0	85	1.47	85.5	72.0	73	63	.....	.....	88.5	81.0	84	77	78	.....
5	83.0	70.5	79	.07	86.0	75.5	73	73	.....	.....	83.0	75.5	82	79	95	.....
6	87.0	68.0	.....	.....	88.0	75.0	86	67	78	.....	85.5	71.0	98	75	87	10.46
7	88.5	73.0	.....	.....	81.0	72.0	61	40	44	.....	85.0	73.0	79	73	72	1.66
8	83.0	72.0	85	.....	81.0	55.0	56	34	40	.....	88.0	75.0	84	70	73	.....
9	83.0	63.0	79	.....	83.5	53.0	66	26	38	.....	90.0	75.0	87	.....	.....	.....
10	83.0	64.5	82	.....	83.0	61.0	75	43	60	.....	91.5	74.0	83	.....	.....	.....
11	84.0	72.5	83	.....	81.0	76.0	56	66	49	.....	91.5	73.0	83	68	77	.....
12	84.5	69.5	91	.....	82.0	66.0	80	.....	76	.....	93.5	74.0	86	.....	.....	.....
13	84.0	71.5	.....	.....	81.0	70.0	74	62	74	.01	89.0	75.0	84	.....	.....	.....
14	83.0	68.0	77	.67	74.0	69.0	98	98	98	.80	90.0	75.0	88	.....	.....	.....
15	84.5	68.5	91	.....	73.5	65.0	97	97	95	3.61	90.5	73.0	89	.....	.....	.....
16	86.5	65.5	98	.....	87.0	61.5	72	56	70	1.74	90.5	71.5	78	.....	.....	.....
17	93.5	68.5	88	.....	89.5	67.0	82	.....	.....	.....	92.0	73.5	88	.....	.....	.....
18	97.0	70.5	62	.....	82.0	68.0	91	.....	.....	.....	91.0	72.0	87	.....	.....	.....
19	85.0	70.5	83	.....	83.0	68.0	79	72	.....	.....	86.0	71.0	82	.....	.....	.....
20	86.0	74.0	.....	.....	84.0	75.0	71	72	71	.....	93.0	73.0	83	.....	.....	.....
21	87.5	71.5	91	.....	82.0	73.0	86	.....	68	.01	84.0	65.0	65	.....	.....	.....
22	86.0	71.0	80	.....	84.0	71.5	82	59	71	.....	91.0	57.5	77	.....	.....	.....

TABLE 1.—*Maximum and minimum temperatures, relative humidity, and rainfall, from Aug. 1 to Oct. 19, 1931, 1932, and 1933, at the United States Acclimatization Field Station, James Island, S. C.*—Continued

Date	1931				1932						1933					
	Temperature		Relative humidity at 8 a. m.	Rainfall (24-hour period) recorded at 8 a. m.	Temperature		Relative humidity at—			Rainfall (24-hour period) recorded at 8 a. m.	Temperature		Relative humidity at—			Rainfall (24-hour period) recorded at 8 a. m.
	Maximum	Minimum			Maximum	Minimum	8 a. m.	1 p. m.	5 p. m.		Maximum	Minimum	8 a. m.	1 p. m.	5 p. m.	
	° F.	° F.	Pct.	Inches	° F.	° F.	Pct.	Pct.	Pct.	Inches	° F.	° F.	Pct.	Pct.	Pct.	Inches
Sept. 23	88.0	69.5	91	.....	82.5	66.0	86	61	64	.05	87.0	62.0	75	.....	.....	.....
24	89.0	72.0	89	.....	82.0	66.5	89	69	.....	.....	87.0	67.0	.....	.....	.....	.....
25	87.5	66.5	77	.....	80.0	69.5	95	.....	82	.....	86.0	70.0	87	.....	.....	.....
26	89.0	76.5	82	.....	74.5	68.0	95	95	93	.15	86.5	66.5	93	.....	.....	.....
27	89.0	67.0	.....	.....	78.0	68.0	98	83	86	.26	85.5	69.0	69	.....	.....	.....
28	77.0	51.0	64	.....	85.0	69.5	91	67	93	.35	87.5	69.5	84	.....	.....	.04
29	77.0	54.0	68	.....	78.5	68.5	93	64	77	.73	88.0	70.5	75	.....	.....	.....
30	78.5	56.5	71	.....	76.5	58.5	65	44	45	.....	90.0	69.0	79	.....	.....	.....
Oct. 1	80.0	61.5	83	.....	75.0	57.0	72	51	61	.....	87.5	72.0	.....	.....	.....	.....
2	81.0	58.5	90	.....	71.0	61.0	78	92	97	.....	84.5	69.0	93	.....	.....	.20
3	80.0	62.5	84	.....	76.5	63.0	95	93	74	1.47	77.0	64.0	76	.....	.....	.01
4	82.0	64.0	.....	.....	79.5	66.0	84	68	74	.25	78.0	61.5	80	.....	.....	.....
5	82.5	66.5	84	.....	81.0	70.0	91	85	89	.....	79.5	64.5	85	.....	.....	.....
6	82.0	61.0	98	.....	69.0	54.5	88	54	57	.35	75.5	57.5	81	.....	.....	.....
7	83.0	62.0	96	.....	67.0	48.5	64	40	57	.....	80.0	50.0	83	.....	.....	.....
8	82.5	66.0	88	.....	74.5	50.5	67	61	.....	.....	78.5	58.0	.....	.....	.....	.....
9	84.0	68.0	86	.04	80.0	63.0	80	63	.....	.....	77.5	61.0	77	.....	.....	.15
10	79.0	61.5	82	.10	78.0	62.5	90	76	78	.....	75.0	46.5	71	.....	.....	.....
11	78.5	58.0	.....	.....	83.0	63.0	93	48	74	.....	76.0	51.5	86	.....	.....	.....
12	84.0	55.5	78	.....	71.0	54.0	73	48	59	.....	78.5	51.5	83	.....	.....	.....
13	77.0	57.0	75	.....	73.0	50.0	89	52	62	.....	82.0	55.5	97	.....	.....	.....
14	84.0	59.0	90	.....	76.0	57.0	80	56	68	.....	74.0	59.5	97	.....	.....	.....
15	84.0	65.5	95	.....	78.0	65.0	93	.....	.....	.....	77.0	61.0	.....	.....	.....	.....
16	81.0	64.0	97	.....	76.0	67.0	95	.....	.....	.59	81.0	68.5	74	.....	.....	.02
17	77.0	47.0	77	.....	79.5	69.0	93	.....	.....	1.59	81.0	68.5	86	.....	.....	.29
18	75.5	51.0	.....	.....	72.0	66.0	88	.....	.....	.01	79.0	62.0	73	.....	.....	.....
19	71.5	49.0	68	.....	84.0	62.5	90	.....	.....	.....	76.0	57.0	69	.....	.....	.....

The moisture content of the seed cotton (sample 1, table 2) at the time the bolls were just beginning to open was 55.9 percent. The drying of the cotton was relatively slow during the first 4 days of the period, the moisture content remaining above 40 percent until September 18, when a few of the bolls were just beginning to become fluffy. On September 19 practically all bolls were fluffy.

A comparison of the data for moisture content of seed cotton and of seed (sample 2, table 2) shows very little difference in the rate of drying during the first 5 days of the test, or until practically all of the bolls were fluffed out. Beginning September 19, the fluffed lint dried more rapidly than the seed. On September 25, the final date of the test, both seed cotton and seed had practically the same moisture percentage, indicating that moisture in excess of that dependent upon atmospheric conditions had been removed.

The seeds from the partially opened bolls, picked before September 18, germinated very slowly, only a few having germinated after being in the germination chambers for 6 days. The seeds from bolls which were allowed to remain in the field longer germinated more promptly, gave higher total germination percentages, and showed fewer dormant.[4] This experiment was begun without knowledge of the fact that many seeds in freshly opened bolls are dormant, and germination tests of the seed samples were begun immediately

[4] SIMPSON, D. M. DORMANCY AND MATURITY OF COTTONSEED. Jour. Agr. Research 50: 429–434, 1935.

after picking. Hence the percentage of germination of the seeds from these samples was considerably lower than would have been the case if they had been stored during the period of dormancy.

TABLE 2.—*Moisture and germination percentages in Tidewater cotton during the period of boll opening, in 1931*

[Bolls tagged Sept. 15]

Bolls harvested	Relative humidity at 8 a. m.	Sample 1		Sample 2					Remarks
		Weight of seed cotton from 10 bolls	Moisture in seed cotton	Weight of seed cotton from 10 bolls	Moisture in seed	Germination		Dormant seed	
						Sixth day	Total		
	Percent	*Grams*	*Percent*	*Grams*	*Percent*	*Pct.*	*Pct.*	*Percent*	
Sept. 15	91	152.9	55.9	159.1	54.5	4	54	16	Dew.
16	98	131.9	50.8	136.2	50.5	1	64	13	Most bolls less than ¼ inch open. Heavy dew.
17	88	133.8	47.8	112.9	47.0	6	58	13	Most bolls ¼ inch open, a few wider.
18	62	127.0	42.6	96.4	31.0	17	59	2	A few samples beginning to fluff. Weather dry.
19	83	114.9	25.3	74.1	26.2	30	68	0	Nearly all bolls fluffy. No dew.
21	91	74.0	14.9	78.9	17.7	24	72	0	All bolls fluffy. Heavy dew.
22	80	72.5	12.8	74.2	14.6	20	83	1	Heavy fog and cloudy. Some bolls showed dew at 10:30 a. m.
23	91	91.4	13.3	83.4	15.5	3	83	2	Heavy fog with moist atmosphere at 10:25 a. m.
24	80	76.3	13.1	75.8	13.7	50	59	0	Weather clear with no dew.
25	77	77.7	12.8	75.2	12.9	61	82	3	No dew.

In 1932 the experiment was enlarged to obtain data (table 3) on several varieties, and the factor of seed dormancy was eliminated by drying and storing the seed for approximately 1 month before the germination tests were made. Three series of tests were conducted, beginning on September 7 and 20 and October 5 and covering periods of varying weather conditions. The test started on September 7 was made with the Tidewater, Cleveland, and Foster varieties. The test started on September 20 comprised these varieties and also Meade. The last test, started on October 5, was made with Tidewater and a strain of sea island.

The method of collecting the data was as follows: At the beginning of each test, approximately 250 bolls of each variety were tagged, normal bolls about one-fourth inch open at the tip being selected. On the date of tagging, 20 tagged bolls of each variety, chosen at random, were clipped from the plants. The seed cotton was removed from the bolls immediately and divided into four samples, one lock from each boll being placed in each sample. Sample 1 was ginned immediately, and the moisture content of the seed was determined; sample 2 was ginned immediately, and the seed was placed in the seed germinator to determine the percentage of germination of fresh seed; sample 3 was used to make an immediate determination of the moisture content of the seed cotton; sample 4 was sun-dried and the seed cotton was stored for 1 month before germination tests of the seed were made. This procedure was repeated each day for 10 successive days on 20 tagged bolls of each variety chosen at random, thus giving data on bolls harvested in daily lots from 1 to 10 days after opening.

TABLE 3.—*Moisture and germination percentages of seed in several varieties of cotton during the period of boll opening in 1932*

BOLLS TAGGED SEPT. 7

Bolls harvested	Rainfall	Tidewater		Cleveland		Foster		Meade		Sea island	
		Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination
	Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Sept. 7	.....	52.0	91	48.7	83	50.9	95	.....	.....	.....	.....
8	.....	43.0	93	38.9	87	41.0	95	.....	.....	.....	.....
9	.....	34.7	91	29.7	88	28.5	94	.....	.....	.....	.....
10	.....	31.2	87	17.3	85	16.0	96	.....	.....	.....	.....
11	.....	13.0	96	15.9	84	12.7	96	.....	.....	.....	.....
12	.....	12.1	96	13.3	94	10.6	93	.....	.....	.....	.....
13	0.01	11.2	97	12.7	87	11.3	97	.....	.....	.....	.....
14	.80	27.2	90	27.5	97	28.3	96	.....	.....	.....	.....
15	3.61	34.0	93	38.7	87	35.9	94	.....	.....	.....	.....
16	1.74	23.3	87	22.8	81	21.6	87	.....	.....	.....	.....

BOLLS TAGGED SEPT. 20

Sept. 20	.....	54.1	97	48.8	93	50.1	95	47.2	87	.....	.....
21	0.01	51.7	97	47.9	89	47.4	86	47.4	86	.....	.....
22	.....	45.6	89	46.3	90	36.0	100	45.5	94	.....	.....
23	.05	38.2	95	34.0	97	30.0	97	40.6	91	.....	.....
24	.....	31.0	91	30.1	93	23.3	94	39.4	94	.....	.....
25	.....	24.9	90	26.7	89	20.9	92	34.8	90	.....	.....
26	.15	27.0	81	28.7	73	23.8	79	34.5	87	.....	.....
27	.26	28.6	66	31.1	77	31.5	90	38.2	46	.....	.....
28	.35	22.5	92	27.1	76	25.2	95	34.5	62	.....	.....
29	.73	.....	78	.....	73	.....	90	.....	41	.....	.....

BOLLS TAGGED OCT. 5

Oct. 5	.....	53.9	80	.....	.....	.....	.....	.....	.....	48.4	96
6	0.35	53.1	88	.....	.....	.....	.....	.....	.....	48.2	97
7	.....	52.2	83	.....	.....	.....	.....	.....	.....	49.0	96
8	.....	48.2	88	.....	.....	.....	.....	.....	.....	41.2	95
9	.....	33.0	92	.....	.....	.....	.....	.....	.....	29.4	96
10	.....	37.8	89	.....	.....	.....	.....	.....	.....	20.2	98
11	.....	24.5	90	.....	.....	.....	.....	.....	.....	17.1	97
12	.....	15.8	94	.....	.....	.....	.....	.....	.....	13.9	92
13	.....	11.3	97	.....	.....	.....	.....	.....	.....	12.3	92
14	.....	13.7	84	.....	.....	.....	.....	.....	.....	13.8	97

The three periods covered by the tests in 1932 afforded widely different weather conditions during the time that the bolls remained in the field. In the first test (started Sept. 7) no rain was recorded from September 7 to 12. The relative humidity for this 6-day period, as taken at 8 a. m., averaged 66 percent, and maximum temperatures of 81° F. or more were recorded each day. The seed from bolls of all varieties dried rapidly, the moisture being reduced from approximately 50 percent on September 7 to about 13 percent on September 11. Rains recorded on September 13, 14, 15, and 16 caused an immediate rise in the moisture content of the seed, but these rains, during the latter part of the test period, did practically no damage to the germinating qualities of the seed.

The second series of bolls, tagged on September 20, dried much more slowly than the first series. On September 21, 0.01 inch of rain was recorded and 0.05 inch on September 23. The average relative humidity, taken at 8 a. m., for the period September 20–25 was 85 percent, 19 points higher than the average for the first 6 days of the first test period. Because of these conditions, samples collected

on the sixth day after opening had from 20.9 to 34.8 percent moisture, whereas samples in the preceding test had had from 10.6 to 13.3 percent moisture after 6 days' exposure in the field. Rains on September 26, 27, 28, and 29 prevented the seed from further drying in the field. Germination percentages were high from samples of all varieties harvested before September 26, but lower germination percentages were obtained from nearly all samples of Tidewater, Cleveland, and Meade harvested after the rains. Seed of the Meade variety dried more slowly than that of the other varieties and showed the greatest amount of deterioration from exposure in the field. Seed of the Foster variety dried more promptly than that of the other varieties and showed practically no loss of germination as a result of the unfavorable conditions.

The third test, begun on October 5, included only the Tidewater variety and sea-island strain. On October 6, 0.35 inch of rain was recorded, and cool weather prevailed during October 6, 7, and 8, the maximum temperatures being 69°, 67°, and 74.5° F., respectively, so that drying proceeded very slowly. With higher temperatures the rate of drying increased, and by October 13 the moisture of the seed of both varieties was reduced to approximately 12 percent. Seed of the sea island dried considerably faster than that of Tidewater, the difference possibly being due to the smaller size of the sea-island bolls. Germination percentages for both varieties remained fairly constant throughout the period of the test, the sea-island seed averaging slightly higher than the Tidewater.

In 1933 further tests on the percentage of moisture and germination of seed during boll opening were made on Tidewater, Coker Wilds, Foster, and Cleveland, and on several strains of sea island. Three series of tests were made, beginning August 1, August 10, and August 28, respectively. Samples were obtained similar to those in 1932 except that the seed cotton from each variety was divided into 2 samples each day instead of 4 as in 1932. These 2 samples were used to make determinations of moisture in the seed cotton when harvested and of germination percentages of the seed after it had been dried and stored for 1 month.

The data (table 4) obtained in 1933 are in accord with those obtained in 1932. In both series, seed in all varieties contained slightly more than 50 percent moisture at the beginning of the opening period, and the rate of reduction in moisture percentages was influenced by rainfall, humidity, and temperature. In the first test, drying of the cotton was slightly delayed by rains on August 4 and 5 but progressed rapidly afterward. The viability of the seed was only slightly affected by these rains. This test was continued for only 8 days, as the bolls were all well opened and dry on August 8. The second series of bolls, tagged on August 10, dried rapidly during the first 3 days of the test, reabsorbed moisture during the rain of August 13, and dried rapidly to approximately 11 percent by August 15. Rains on August 16, 17, 18, and 19 caused reabsorption of moisture to above 30 percent. Excellent germination was obtained from all varieties of seed harvested before August 19. For all varieties, except Foster, lower germination percentages were obtained from seed from bolls harvested on August 19.

TABLE 4.—*Moisture in seed cotton and germination of seed in several varieties of cotton during the period of boll opening in 1933*

BOLLS TAGGED AUG. 1

Bolls harvested	Rainfall	Tidewater		Coker Wilds		Foster		Cleveland	
		Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination
	Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Aug. 1		53.7	92	52.4	91	51.4	93	53.9	86
2		47.1	89	37.4	85	39.3	96	42.2	87
3		32.2	92	24.7	92	21.4	89	24.8	87
4	0.50	26.6	82	18.3	91	16.8	89	14.9	79
5	.44	22.0	79	18.8	85	15.9	92	16.6	89
6		15.6	90	14.2	93	11.3	96	13.6	88
7		11.3	91	9.4	89	9.2	91	8.6	74
8		11.4	85	9.5	92	9.4	95	9.3	78

BOLLS TAGGED AUG. 10

Aug. 10		53.2	89	52.5	94	51.0	93	51.9	81
11	0.01	46.3	99	40.7	90	46.3	88	46.3	95
12		33.8	90	23.2	95	26.9	95	25.1	90
13	1.74	38.7	86	34.2	97	32.3	95	48.7	86
[1] 14	.01	14.8	94	13.2	92	16.8	96	12.6	80
15		11.5	92	10.7	100	12.4	95	9.9	95
16	.28	15.4	97	17.6	89	18.5	92	19.0	88
17	.14	31.7	93	31.2	95	34.2	93	39.1	86
18	.35	25.4	84	27.2	98	30.9	93	30.5	90
19	.38	31.3	67	45.4	83	37.2	92	41.4	78

[1] All moisture determinations after Aug. 13 were made on seed instead of on seed cotton.

The third series in this test was begun on August 28, data being obtained on Tidewater and on the Seabrook, Westberry, and Andrews strains of sea island. The weather during the period covered by this test was unfavorable for harvesting cotton. Rain was recorded on August 28, 30, and 31, and on September 1, 2, and 6. The data on moisture and germination percentages in this series (table 5) are of particular interest in comparing the rate of drying of the seed of the upland type, represented by Tidewater, with the seed of the sea-island strains. While the frequent rains and high humidity prevented rapid drying in any of the varieties, from the second to the sixth day of the period, the Tidewater seed contained from 15 to 20 percent more moisture than the seed of the sea-island strains harvested on the same dates.

The adverse weather conditions seriously affected the germination of the Tidewater seed harvested after the first day of the test period. Of the seed from bolls harvested on August 28, 91 percent germinated, but thereafter germination percentages were in general progressively lower as the length of exposure in the field increased. Only 13 percent of the seed from bolls harvested on September 6 germinated. Seed from the sea-island strains gave good germination percentages in practically all cases until after the heavy rains of September 6.

TABLE 5.—*Moisture and germination percentages of seed in the Tidewater variety as compared with that in several strains of sea-island cotton during the period of boll opening in 1933*

[Bolls tagged Aug. 28, 1933]

Bolls harvested	Rainfall	Tidewater		Sea island strains					
				Seabrook		Westberry		Andrews	
		Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination
	Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Aug. 28	0.01	54.6	91	49.2	96	43.6	93	48.1	96
29		53.6	81	36.4	95	32.3	93	37.1	95
30	.17	47.8	72	29.9	94	28.1	94	36.1	89
31	.50	45.0	60	28.1	91	27.8	89	28.9	96
Sept. 1	1.15	45.9	57	32.2	96	36.5	84	37.6	92
2	.01	40.5	28	21.4	90	21.4	89	19.5	93
3		20.2	20	14.9	91	14.5	81	13.6	82
4		14.6	20	12.5	64	12.0	82	11.7	91
5		14.9	29	13.8	89	13.6	92	13.2	93
6	10.46	55.5	13	44.0	69	52.4	50	43.0	79

The foregoing tests show that the reduction of moisture in the seed cotton and seed during the period of boll opening proceeds rapidly in periods of dry weather and high temperature. Under favorable conditions at James Island, cotton may be dry enough to pick 5 days after the bolls begin to open. In periods of rainy weather, the drying process is delayed and the moisture content of both seed cotton and seed may be considerably increased by the reabsorption of moisture. Rains which delay the drying-out process usually cause deterioration of the seed. Among the varieties tested, sea island and Foster dried more rapidly than the others and were more resistant to seed deterioration when exposed to unfavorable weather in the field.

Seeds from bolls which were just beginning to open were found to be viable and, if properly dried and stored for a short time, gave higher germination percentages than seeds which were exposed in the field for a greater length of time. From this fact it may be assumed that the picking of partially opened bolls does not lower the viability of the bulk seed of which they constitute a part, provided they are dried promptly after picking.

Owing to the high moisture content of freshly picked seed cotton in the coastal section of the Southeastern States, caused by climatic conditions, special precautions are necessary to prevent injury to the cotton. Farms usually are provided with drying platforms on which the cotton is spread and exposed to the sun for a few hours to remove the excess moisture. Drying for 1 day in bright sunshine usually is enough to reduce the moisture content sufficiently to permit safe storage or ginning. Experience has shown that seed cotton having about 10 percent moisture may be ginned safely or may be stored in bulk with little danger of heating. When more cotton is harvested than can be exposed in the available space, or when periods of cloudy weather occur, several days may elapse before it is possible to dry the cotton. Under such conditions, the damp cotton usually is stored in small piles or is spread as thinly as possible on the available floor space. Data obtained in 1932 on damp cotton stored for 6 days indicated that no deterioration in germination of the seed occurred during this short period of storage.

DETERIORATION OF SEED IN THE FIELD

It has been shown that rain occurring during the period of boll opening delays the opening process and reduces the percentage of viable seed. Further evidence of the effect of weather conditions on the viability of seed exposed in the field is shown by experiments conducted in 1931, 1932, and 1933. These experiments were planned to determine the moisture and germination percentages of seed from bolls exposed in the field for 7 and 14 days, respectively, after boll opening began.

On August 12, 1931, 200 bolls of the Tidewater variety which were just beginning to open were tagged. Rain recorded on August 12, 13, 14, and 15 totaled 2.75 inches. On August 19, 100 tagged bolls were picked for tests of moisture and germination. These bolls had been delayed in opening by the wet weather, and nearly all locks were still compact when the cotton was picked. The moisture content of the seed from this sample was 24.5 percent and the germination only 33 percent. The remaining half of these bolls were picked on August 26. As no rain had fallen between August 15 and 26, and as the period August 17–26 was one of comparatively low atmospheric humidity, these bolls were dry and fluffy. The seed contained 10.0 percent moisture and showed no further deterioration, the germination percentage being 33.

A second series of bolls was tagged on August 19 and picked on August 26. Dry weather and low humidity prevailed during this period, and the bolls were well opened and the locks fluffy on August 26. The seed from these bolls, in contrast to those opening during the preceding week, contained 9.6 percent moisture and gave a germination of 87 percent.

A group of bolls was tagged on August 26, and half of them were picked on September 2 and the remainder on September 10. Heavy rains were recorded on August 28 and 31 and on September 3 and 4, and a shower on September 5. The seed from the bolls which opened during the week of August 26 to September 2 contained 22.8 percent moisture and had a germination percentage of 48. The seed from the bolls which remained in the field for the second week and were exposed to further rains contained 12.7 percent moisture and had a germination percentage of 30. The rains of September 3, 4, and 5 had delayed the drying-out of the seed and further lowered their viability.

A group of bolls tagged on September 11 was picked on September 18 and 25. These bolls were exposed to 0.67 inch of rain on September 14, this being the only rain during the period of the test. The seed from the first series of bolls, picked on September 18, contained 12.3 percent moisture and 73 percent of them germinated. The seed from the second series, picked on September 25, contained 13.4 percent moisture and 58 percent of them germinated, indicating that the rain on September 14 caused further deterioration of the seed in the bolls left in the field. The last group of bolls was tagged on September 18 and picked on September 25 and October 2. The series picked on September 25, after being open 1 week in the field, had a germination percentage of 84 and contained 13.4 percent moisture. The series picked on October 2 had a germination percentage of 81 and contained 9.2 percent moisture. No rain fell during this 2-week period.

The germination percentages were obtained from tests made immediately after the samples were picked. Other experiments have shown that there is some degree of dormancy in freshly picked cottonseed.[5] However, since these samples were obtained from bolls open in the field from 7 to 14 days, the number of dormant seed would be smaller than from partially opened bolls.

The data obtained in 1931 indicated that bolls opening and picked during a rain-free period would yield seed of high germination, and there was also some evidence that the seed was more likely to be damaged if rain fell shortly after the bolls began to open than if it fell after the locks had fluffed out. It has been observed that partially opened bolls are very susceptible to attack by fungus and bacterial infections and that in periods of rainy weather many partially opened bolls become so severely infected that they fail to open further during subsequent fair weather.

Further studies of cottonseed deterioration in the field were conducted in 1932. Data similar to those obtained on Tidewater cotton in 1931 were collected on Tidewater, Cleveland, Foster, and Meade (table 6). In order to eliminate dormancy as a factor, all seed samples were thoroughly dried and stored for approximately 1 month before the germination tests were made.

TABLE 6.—*Moisture and germination percentages of seed from cotton exposed to varying weather conditions in the field in 1932*

Bolls tagged	Bolls picked	Tidewater		Cleveland		Foster		Meade	
		Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
BOLLS PICKED 1 WEEK AFTER TAGGING									
Aug. 16	Aug. 23	33.8							
23	30	23.0	57						
30	Sept. 6	11.8	84						
Sept. 9	16	39.4	90	38.3	90	36.0	95		
15	22	11.0	73	11.3	84	10.5	89		
22	29	27.0	42	15.6	54	13.7	81	23.7	55
29	Oct. 6	24.1	75	17.5	83	13.1	80	31.3	51
Oct. 6	13	10.2	86						
BOLLS PICKED 2 WEEKS AFTER TAGGING									
Aug. 16	Aug. 30	18.4	53						
23	Sept. 6	12.0	51						
31	14	26.7	66						
Sept. 8	22	10.4	80	10.3	90	10.0	98		
15	29	12.5	47	14.5	52	12.4	77		
22	Oct. 6	19.1	33	16.9	60	17.2	77	21.8	57
29	13	9.9	87	9.7	80	9.8	91	10.1	76

As shown in table 1, the only rain-free periods of more than 4 days during these tests were August 26–September 12, inclusive, and October 7–15. The data in table 6 show that good seeds were obtained during these rain-free periods, and that germination percentages were considerably lower during periods of rainy weather. The Tidewater, Cleveland, and Meade varieties appeared equally susceptible to injury from wet weather, but the Foster variety gave a considerably higher average germination throughout the period of the test.

[5] SIMPSON, D. M. See footnote 4.

In the season of 1933, experiments on the deterioration of seed in the field were continued and the work was enlarged to provide more complete data through the picking season. Determinations of moisture and germination percentages were made on seed from the Tidewater, Coker Wilds, Foster, and Cleveland varieties. These determinations were made on seeds from open bolls exposed in the field for 7 and 14 days. The first group of bolls was tagged on August 1, and a new group in each variety was tagged each day thereafter, except Sundays, to and including August 25. Thus the daily fluctuations in moisture and germination of seed from bolls of known age were ascertained for the four varieties being tested (table 7). All moisture determinations were made on seed ginned and weighed immediately after removal from the bolls, and all germination percentages were made on seed which had been thoroughly dried and stored for approximately 1 month.

TABLE 7.—*Moisture and germination percentages of seed from cotton exposed to varying weather conditions in the field in 1933*

BOLLS PICKED 1 WEEK AFTER TAGGING

Bolls tagged	Bolls picked	Tidewater		Cleveland		Foster		Coker Wilds	
		Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Aug. 1	Aug. 8	11.5	95	8.6	89	10.0	91	9.7	97
2	9	11.8	93	9.9	90	11.3	95	10.7	94
3	10	10.6	86	9.7	91	9.7	95	8.8	89
4	11	11.4	95	8.7	94	10.6	91	9.8	84
5	12	9.6	93	8.3	83	9.9	97	8.8	91
7	14	12.2	93	10.2	93	10.9	95	11.4	95
8	15	10.3	91	9.8	90	10.3	94	10.5	96
9	16	20.7	86	18.7	87	18.2	86	16.2	92
10	17	33.1	90	45.0	90	39.9	94	35.0	92
11	18	25.2	92	31.2	84	31.0	92	29.4	92
12	19	33.5	58	43.6	67	43.2	87	38.2	73
14	21	42.9	43	43.0	58	46.5	81	44.1	85
15	22	43.3	42	35.6	43	35.4	94	38.8	70
16	23	30.8	46	19.6	67	25.4	74	23.1	60
17	24	14.2	77	11.8	69	13.0	78	13.0	53
18	25	12.7	72	12.2	52	12.4	81	13.1	74
19	26	14.1	73	13.4	66	13.3	90	13.6	73
21	28	10.8	60	9.9	76	10.5	89	10.6	74
22	29	11.8	76	10.2	69	11.5	75	10.9	58
23	30	26.0	40	28.8	73	31.5	92	32.3	80
24	31	27.1	66	29.9	81	25.4	99	24.0	87
25	Sept. 1	38.9	51	44.6	83	35.5	82	40.7	73

BOLLS PICKED 2 WEEKS AFTER TAGGING

Aug. 1	Aug. 15	10.0	87	9.0	86	9.1	92	9.1	96
2	16	15.9	82	15.6	87	17.5	97	17.8	93
3	17	34.4	89	34.0	75	33.0	93	32.2	84
4	18	22.9	75	21.8	78	24.1	96	22.3	89
5	19	43.4	67	42.8	73	40.2	88	35.4	75
7	21	41.2	77	36.5	80	40.3	84	39.7	61
8	22	30.2	51	28.3	76	28.2	77	27.3	75
9	23	13.4	56	10.6	79	12.3	70	11.6	62
10	24	11.3	57	10.6	85	11.0	69	11.6	70
11	25	12.8	66	13.4	63	10.5	53	13.2	61
12	26	12.0	31	11.3	57	11.4	59	11.5	48
14	28	10.4	34	9.7	45	9.9	76	10.8	44
15	29	11.7	45	10.7	43	11.4	67	11.1	42
16	30	25.1	16	29.2	33	29.6	64	31.9	37
17	31	22.6	48	26.0	49	24.9	73	26.4	47
18	Sept. 1	33.3	31	35.7	28	38.7	62	33.5	39
19	2	18.7	38	15.8	27	17.6	66	19.8	32
21	4	12.3	37	11.2	54	12.1	63	11.8	49
22	5	13.6	32	13.7	40	13.5	75	14.1	53
23	6	54.5	37	69.2	----	67.1	72	63.9	----
24	7	31.8	17	37.3	30	27.6	70	42.8	----
25	8	15.5	11	10.2	16	10.1	80	14.7	64

The weather records (table 1) for the period of this experiment show that rain fell on 20 days of the 39-day period August 1–September 8. All bolls harvested had been rained upon in the field. Although several rains were recorded, the weather during the period August 1–12 was favorable for harvesting cotton, as the rains were not excessive and the relative humidity during the day was comparatively low. Seeds of all varieties from bolls tagged before August 12 and harvested before August 19 gave high germination. Although the seed from bolls harvested on August 16 and 17 contained excessive moisture when harvested, the germination was not seriously affected. Rain was recorded on 15 days of the 23-day period August 16–September 7. Bolls opening during this period of rainy weather did not dry out promptly and the seed contained excessive moisture during practically the entire time that they were exposed in the field. Germination percentages were low in the Tidewater, Coker Wilds, and Cleveland varieties when exposed for 7 days, and in all varieties when exposed for 14 days. The Foster variety, as in 1932, showed less susceptibility to adverse conditions than the other varieties of the test, and when exposed for only 7 days produced good seed. Bolls of the Foster variety tagged on August 23, 24, and 25 remained in the field during one of the heaviest rainfalls on record in this section and still gave germination percentages of 72, 70, and 80, respectively. The seed from bolls of this variety, open for 14 days and harvested on September 6, contained 67.1 percent moisture when harvested, and yet when they were dried and stored for approximately 1 month, 72 percent germinated. This greater resistance to adverse weather conditions shown by seed of the Foster variety indicated the possibility of increasing the resistance to field deterioration in other varieties by selection.

The number of varieties upon which comparative data have been obtained is so limited that no general conclusions can be drawn as to the plant or seed characters which offer most resistance to field deterioration. However, it is probable that density of plant foliage, size of bolls, and other factors which influence the rate of drying of the seed are the more important. Among the varieties tested, all strains of sea island cotton have shown high percentages of seed germination even under adverse weather conditions. The absence of fuzz on the sea-island seed has been suggested as a possible reason for the greater resistance to field deterioration, and it may be that some advantage from more rapid drying results from this slick-seed character. However, Meade seed, which is also fairly free from fuzz, shows no advantage over that of such varieties as Tidewater, Coker Wilds, and Cleveland, which bear fuzzy seed.

SUMMARY

Seasonal fluctuations in the germination of cottonseed have been attributed to climatic conditions during the harvesting season, but the definite relationship of rainfall, humidity, and temperature to the viability of the seeds has received little attention. Experiments conducted at James Island, S. C., in 1931, 1932, and 1933, under conditions of frequent rainfall and high humidity, provide information on these conditions.

Cotton harvested at James Island normally contains excessive moisture. Determinations of the moisture content of seed during the period of boll opening showed that seed from bolls just cracking open contained approximately 50 percent moisture and that seed from partially opened bolls, which are ordinarily harvested by the pickers, may contain more than 28 percent moisture. Dry weather caused rapid reduction in the moisture content of the seed and seed cotton, but rainy, humid, or cool weather prevented drying and delayed boll opening.

The low viability of seed harvested in unfavorable weather indicates that seed deterioration occurs in the field before harvesting. Seed from bolls just opening, when dried and stored for a short time, gave higher germination percentages than seed which had been exposed for a longer period in the field.

Data on the viability of seed taken from bolls exposed for varying lengths of time in the field showed that deterioration of the seed was correlated with rains or humid conditions which prevented the prompt drying of the seed cotton after the bolls began to open. Seed from bolls opening and harvested during periods of dry weather gave higher germination percentages than did seed from bolls opening and harvested during rainy weather. Differences in resistance to field deterioration were apparent among the varieties tested, and the possibility of improvement in the germinating qualities of cottonseed by selective breeding is suggested.

RELATION OF MOISTURE CONTENT AND METHOD OF STORAGE TO DETERIORATION OF STORED COTTONSEED[1]

By D. M. SIMPSON[2]

Associate agronomist, Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

Experiments conducted at the United States Acclimatization Field Station, James Island, S. C., have shown that rapid loss of viability occurs in cottonseed stored under the humid conditions of the South Carolina coastal district. Under ordinary storage conditions at James Island seed may be safely kept for 2 years, but rapid loss in viability occurs during further storage. In the arid sections of the West, cottonseed has been kept for more than 20 years without complete loss of viability, and seed stored at Washington, D. C., has given fair germination percentages after 10 years.

DETERIORATION OF SEED IN ORDINARY STORAGE

The short life of cottonseed in ordinary storage at James Island is shown by the data (table 1) from a series of experiments begun in 1930 to determine the effect of different methods of storage on the rapidity of deterioration.

The storage house used for these experiments is a one-story frame building constructed on piers 8 feet above the ground to allow free circulation of air. The building is divided into three rooms, each approximately 10 by 15 feet, sealed overhead with matched ceiling. Each room has 2 windows, 1 on the north and 1 on the south side. These windows are equipped with glass sash and tight wooden shutters. Ventilators that may be opened or closed are provided under each window at the floor level and in the center of the ceiling of each room.

Different conditions of storage were provided in each room by controlling ventilation and sunlight; other conditions were as uniform as possible. The control of ventilation in the various rooms was as follows:

Room 1.—All shutters and ventilators open on dry days when humidity was below 80° and closed on wet days and at night.

Room 2.—All shutters and ventilators closed at all times.

Room 3.—Ceiling ventilator and window shutters open at all times. Floor ventilators open on dry days when humidity was below 80°, and closed on wet days and at night.

[1] Received for publication Sept. 25, 1934; issued May 1935.

[2] The writer wishes to acknowledge the assistance of E. H. Toole, physiologist, Division of Seed Investigations, Bureau of Plant Industry, in planning these experiments.

TABLE 1.—*Moisture and germination percentages of sea-island cottonseed stored at James Island, S. C., November 1930 to September 1933*

Date	Bags stacked on floor						Bags stacked on lattice					
	Bottom bag		Middle bag		Top bag		Bottom bag		Middle bag		Top bag	
	Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
STORAGE ROOM 1												
Nov. 24, 1930	11.71	95	11.42	96	11.34	89	11.17	89	11.04	89	11.09	91
Mar. 16, 1931	11.60	94	11.20	96	11.30	97	11.10	90	10.90	90	11.00	88
July 13, 1931	11.27	83	10.78	92	10.42	90	10.84	89	10.61	90	10.34	90
Nov. 24, 1931	11.30	60	10.65	91	10.61	91	10.58	83	10.47	88	10.46	83
Mar. 20, 1932	11.72	57	11.38	82	11.84	87	11.16	79	11.11	82	11.23	77
July 6, 1932	11.15	17	10.76	50	10.92	39	10.92	76	10.76	69	11.03	54
Nov. 22, 1932	12.65	4	11.02	18	11.63	13	11.19	44	10.68	47	11.18	41
Mar. 14, 1933	13.09	9	11.05	43	11.90	16	11.19	47	10.76	51	11.69	34
June 27, 1933	12.09	1	10.91	3	11.01	0	10.75	8	10.86	17	10.95	1
Sept. 5, 1933	12.28	0	11.32	0	11.73	0	11.44	6	11.13	5	11.01	1
STORAGE ROOM 2												
Nov. 24, 1930	12.47	88	13.23	92	11.95	96	10.66	89	10.86	86	11.54	87
Mar. 16, 1931	12.05	95	11.10	94	11.80	93	10.80	92	10.70	91	11.30	92
July 13, 1931	11.56	88	10.79	95	10.79	90	10.69	92	10.64	93	10.54	88
Nov. 24, 1931	11.73	42	10.80	84	10.74	79	10.71	82	10.75	93	10.73	85
Mar. 20, 1932	12.22	45	11.84	79	11.86	64	11.62	74	11.28	77	11.72	74
July 6, 1932	11.95	9	11.10	42	11.32	28	11.27	67	10.99	69	11.26	50
Nov. 22, 1932	12.57	0	11.33	12	11.78	0	11.51	25	10.79	39	11.43	20
Mar. 14, 1933	12.13	0	11.65	18	12.37	1	11.21	31	10.84	46	11.90	20
June 27, 1933	11.90	0	11.15	0	11.35	0	11.01	1	11.22	10	11.45	0
Sept. 5, 1933	12.22	0	11.46	0	11.58	0	11.42	1	11.16	3	11.36	0
STORAGE ROOM 3												
Nov. 24, 1930	11.81	95	11.41	93	11.70	94	10.86	92	11.07	95	11.26	89
Mar. 16, 1931	11.30	93	11.15	98	11.35	96	11.05	87	11.00	90	11.30	96
July 13, 1931	11.01	87	10.20	84	10.16	96	10.89	91	10.54	88	10.52	82
Nov. 24, 1931	10.99	81	10.31	85	10.18	87	10.67	80	10.46	86	10.49	77
Mar. 20, 1932	11.17	81	10.94	83	11.27	81	11.47	79	11.20	77	11.68	72
July 6, 1932	10.82	66	10.50	74	10.67	63	10.93	56	10.68	61	10.90	60
Nov. 22, 1932	10.89	38	10.77	49	11.19	40	11.22	32	10.58	26	11.21	29
Mar. 14, 1933	10.98	50	11.07	54	11.66	29	10.91	44	10.64	50	11.62	28
June 27, 1933	10.75	7	10.33	7	10.42	2	10.81	7	10.84	3	10.87	0
Sept. 5, 1933	11.22	7	10.85	7	10.63	2	11.20	7	10.79	0	10.79	0

Sea island cottonseed, grown at Wadmalaw Island, S. C., in 1929, was used for these tests. The seed was stored in bins from December 1929 until the fall of 1930, when the storage tests were begun. The seed was then placed in bags containing approximately 100 pounds each, and the bags were piled in stacks, 2 bags to the tier, each stack containing 12 bags. Two stacks were placed in each room, along the north wall. One stack was started on the floor and the other was raised from the floor about 8 inches by a lattice framework. Initial moisture and germination tests were made on this seed on November 24, 1930, samples being drawn from three bags in each stack, representing the bottom, middle, and top. Subsequent determinations were made on seed from the same bags.

The average germination of the seed from the 18 bags, when placed in storage on November 24, 1930, was 91.4 percent, and the average moisture content was 11.48 percent. During the period from Novem-

ber 24 to July 13, 1931, there was little change in germination percentage in the seed from any of the bags on which tests were made, the average germination percentage for all the bags on July 13 being only 2.1 percent less than the initial germination.

The first decided drop in germination came during the period July 13–November 24, 1931. The tests made on November 24 showed decreased germination in practically all cases, but the most pronounced decreases were in seed from the bottom bags of the stacks piled on the floor in rooms 1 and 2. The seed from the stacks placed on the lattice showed only a slight decrease in germination at this date. After November 24, 1931, the percentage of germination of the seed in all storage rooms declined at an increasingly rapid rate. On March 20, 1932, when the seed was 2½ years old, the average germination of all seed in storage was 75 percent. On March 14, 1933, the average germination of all seed in storage had dropped to 31.7 percent.

The high degree of fluctuation after July 1932 in germination percentages of seed from the individual bags indicates that even the viable seeds were considerably weakened and required optimum conditions for germination. Seed stored in room 3, which received the greatest amount of sunlight and ventilation, in general gave slightly higher germination percentages during the latter part of the storage period than the seed stored in rooms 1 and 2. Seed stored in room 2, which received no sunlight or ventilation, showed the most rapid decline.

As previously noted, the seed from the bottom bags in the stacks on the floor of rooms 1 and 2 was the first to show definite decreases in germination percentages. The moisture content of the seed in these bags was slightly higher than in the middle or top bags from the same stack. In room 1, the average moisture percentage of the seed in the bottom bag from November 24, 1930, to November 24, 1931, was 11.47 percent, as compared with 11.01 percent in the middle bag and 10.92 percent in the top bag. In room 2, the average moisture content of the seed in the bottom bag was 11.95 percent as compared with 11.48 percent and 11.32 percent in the middle and top bags, respectively.

The results of the foregoing experiments show that in normal dry storage sea-island cottonseed may be preserved under the conditions prevailing in the coastal district of South Carolina for 2 years without material loss of viability. Some decrease in germination was evident during the first 6 months of the third year, but the seed retained sufficient viability for planting purposes when 2½ years old.

RELATION OF MOISTURE CONTENT TO DETERIORATION OF SEED

A series of tests was begun in July 1930 to determine the effect of moisture content on the keeping qualities of stored cottonseed. For these tests, 700 pounds of sea-island cottonseed, harvested in the fall of 1929, was thoroughly mixed, and samples taken to determine the moisture and germination percentages. Three 100-pound lots of this seed were stored as follows:

Lot 1.—Air-dried seed stored in can with perforated lid.
Lot 2.—Air-dried seed stored in can with tight lid.
Lot 3.—Air-dried seed stored in burlap bag.

At the beginning of the tests, these air-dried seed contained 10.77 percent moisture and 90 percent germinated.

The remainder of the seed was exposed to the sun for approximately 7 hours and was then divided into four 100-pound lots and stored as follows:

Lot 4.—Sun-dried seed stored in can with perforated lid.
Lot 5.—Sun-dried seed stored in can without lid.
Lot 6.—Sun-dried seed stored in can with tight lid.
Lot 7.—Sun-dried seed stored in burlap bag.

At the beginning of the tests, these sun-dried seeds contained 7.8 percent moisture and gave a germination of 85 percent. The initial determinations of moisture and germination on these lots were made in the laboratory of the Division of Seed Investigations, Bureau of Plant Industry, at Washington, D. C., from representative samples transmitted in sealed containers. All the other determinations of moisture and the germination percentages (table 2) were made at James Island. Beginning December 1, 1930, determinations of moisture and germination were made on each of the seven seed lots, usually at approximately 2-month intervals, until March 12, 1934. During the period of storage, the seed was kept in room 1 of the seed house. The cans designated as sealed were fitted with tight lids, but were not airtight, and were opened for sampling at regular intervals. All samples were drawn with a sampling tube designed to secure a composite sample from a longitudinal section through the bag or can.

TABLE 2.—*Moisture and germination percentages of sea-island cottonseed, air-dried and sun-dried, stored in cans and bags at James Island, S. C., July 1930 to March 1934*

Date	Stored in cans										Stored in bags			
	Lot 1 (air-dried; lid perforated)		Lot 4 (sun-dried; lid perforated)		Lot 5 (sun-dried; not sealed)		Lot 6 (sun-dried; sealed)		Lot 2 (air-dried; sealed)		Lot 7 (sun-dried)		Lot 3 (air-dried)	
	Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination	Moisture	Germination
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
July 27, 1930	10.77	90	7.80	85	7.80	85	7.80	85	10.77	90	7.80	85	10.77	90
Dec. 1, 1930	11.14	91	8.36	97	8.16	87	8.12	89	11.36	91	10.60	90	11.62	95
Jan. 20, 1931	10.90	88	8.20	94	8.07	90	7.91	94	11.22	95	10.52	93	11.52	92
Mar. 16, 1931	10.30	91	8.50	95	7.70	91	7.80	93	11.15	90	10.50	91	11.05	92
May 26, 1931	10.82	92	8.17	90	7.90	95	7.86	92	10.72	86	10.09	94	10.75	95
July 20, 1931	10.85	81	8.41	95	7.85	91	8.01	92	10.98	87	10.41	89	10.81	95
Sept. 21, 1931	10.44	84	7.74	83	7.39	87	7.23	85	10.80	85	10.32	81	10.56	91
Nov. 16, 1931	10.63	91	8.31	91	7.75	90	7.80	92	10.84	84	9.91	88	10.70	86
Jan. 15, 1932	11.83	85	9.39	86	8.98	85	8.83	89	11.99	85	11.49	87	11.80	88
Mar. 14, 1932	11.22	79	8.98	84	8.44	87	8.44	91	11.60	84	10.99	85	11.34	88
May 9, 1932	11.64	81	8.95	85	8.30	84	8.56	85	11.88	71	10.83	71	10.91	81
July 7, 1932	10.87	72	8.57	77	8.85	78	7.74	86	11.02	62	10.76	49	10.91	39
Sept. 1, 1932	10.54	39	8.54	84	8.22	81	7.78	85	11.05	39	10.66	42	11.03	41
Oct. 27, 1932	11.53	48	9.04	84	9.28	86	8.37	87	11.30	39	11.17	64	11.74	45
Jan. 4, 1933	11.37	44	8.94	86	9.14	87	8.40	90	11.26	32	11.20	35	11.59	31
Feb. 27, 1933	11.55	33	9.08	85	9.29	90	8.39	93	11.25	24	11.28	56	11.64	36
Apr. 24, 1933	11.21	34	9.15	81	9.58	89	8.20	82	11.54	19	11.24	38	11.31	17
June 20, 1933	11.14	28	9.09	87	9.28	80	8.12	85	11.51	16	10.99	18	11.20	11
Aug. 9, 1933	10.35	0	8.96	85	8.97	79	8.21	80	11.12	1	11.07	6	11.42	1
Oct. 3, 1933	11.20	0	9.27	80	9.21	77	8.20	81	11.34	0	10.89	0	11.27	0
Dec. 4, 1933	11.32	0	9.30	89	9.35	81	8.31	88	11.46	0	10.81	0	11.11	3
Jan. 8, 1934	11.35	0	9.23	80	9.32	78	8.28	89	11.38	0	11.05	0	11.02	0
Mar. 12, 1934	11.22	0	9.20	86	9.11	78	8.23	93	11.18	0	10.58	0	10.90	0

The data in table 2 show that the sun-dried seed stored in a burlap bag regained moisture rapidly. After approximately 4 months' storage, this seed contained 10.6 percent moisture, only 1.02 percent less than the air-dried seed stored under the same conditions. The germination and moisture percentages of the two lots stored in bags were approximately equal during the remainder of the storage period. Both lots germinated well until May 1932, after which deterioration was rapid. No appreciable advantage was gained by sun-drying and re-storing in burlap bags.

A comparison of the results obtained with air-dried seed in lots 1 and 2, stored in cans, and lot 3, stored in a burlap bag, show no appreciable difference in moisture or germination percentages throughout the tests. None of these lots of seed showed a fluctuation of more than 1.5 percent in moisture content during the period of storage, the maximum moisture content in all cases being below 12 percent.

The importance of moisture as a factor in seed deterioration is shown by the data obtained from the sun-dried seed stored in cans. Lots 4, 5, and 6, in which the moisture content was reduced to 7.80 percent before storage on July 27, 1930, retained their viability with little impairment up to March 1934. Over this period of approximately 3½ years, the moisture content of the seed in the unsealed can fluctuated between 7.8 and 9.58 percent, there being a gradual rise in moisture content as the storage period lengthened. The seed in the sealed can fluctuated between 7.8 and 8.83 percent moisture, the last determination, made on March 12, 1934, being 8.23 percent. During the latter part of the storage period, the average germination percentage of the sun-dried seed in the sealed can was slightly higher than that of the seed in the unsealed can or in the can with perforated lid.

These tests indicate that sea-island cottonseed may safely be stored for 4 or more years if the moisture content of the seed is not in excess of about 9 percent. Sun-dried seed stored in tin containers reabsorbed moisture very slowly, even though unsealed. When dried and stored in burlap bags, seed regained moisture rapidly. The type of storage did not materially affect the keeping qualities of the seed except as it prevented the reabsorption of moisture. Throughout the storage period there was no appreciable difference between the germination percentages of air-dried seed stored in a sealed can and air-dried seed stored in a burlap bag.

EFFECT OF MOISTURE CONTENT ON GERMINATION OF SEED IN DIFFERENT TYPES OF STORAGE

Further experiments on the relation of moisture content of cottonseed to deterioration in storage were begun in 1931 with seed of upland cotton. Four lots of seed, ranging from 8.75 to 13.78 percent in moisture content, were divided and stored in three ways, namely, in wooden bins, in burlap bags, and in tin containers.

Bulking the seed in piles or bins probably is the most common method of storage. The bins used in this experiment were 2 feet wide, 4 feet long, and 4 feet deep, constructed of matched lumber, and not covered.

The seed lots were obtained from a bulk lot of gin-run seed and subjected to various treatments to obtain the desired moisture content in each lot. The seed was grown in 1931, and the low initial germina-

tion was due to deterioration in the field [3] before harvesting and not to damage in storage.

Lots 1 and 2 represented air-dried and sun-dried seed and contained 9.59 and 8.75 percent moisture, respectively. Lots 3 and 4 after being wet to various degrees were passed through a drying machine to equalize the moisture and to dry them to the desired moisture content. These lots were placed in storage on November 3, 1931. Moisture and germination tests were made on each lot on November 3 and at frequent intervals thereafter until April 24, 1934.

Although the moisture content of the four lots of seed stored in bins (fig. 1, *A*) ranged from 8.75 to 13.78 percent when the seed was stored in November 1931, a difference in moisture content of only about 1 percent existed by November 1932. The dried seed, lots 1 and 2, showed no appreciable loss in vitality until June 1933, a period of 19 months. Seed wet to 11.16 percent moisture showed a decrease in germination percentage in 10 months, and seed wet to 13.78 percent showed a consistent decrease in 8 months.

The four seed lots stored in bags, being more exposed to atmospheric humidity, reached a point of uniform moisture content much more rapidly than the seed stored in bins. Although there was a difference of 5.03 percent in the moisture content of the four lots when first stored (fig. 1, *B*), after a period of 6 months the difference was less than 1 percent. While the dried seed stored in bags absorbed moisture a little more rapidly than those stored in bins, no appreciable difference in germination of these lots was shown. However, the seeds which were wet to 11.16 and 13.78 percent moisture and stored in bags dried out to a normal moisture content more rapidly than similarly treated seeds stored in bins, and remained viable for a longer period.

The importance of moisture as a factor in cottonseed deterioration is illustrated in the data from the four lots stored in tin containers (fig. 1, *C*). Like those stored in bins and in bags, these four lots contained moisture ranging from 8.75 to 13.78 percent when stored in November 1931. The tin containers, each of which held about 100 pounds of seed, were covered but not sealed airtight, and were opened for sampling at regular intervals. Some fluctuations in the moisture content of the samples drawn from the different lots were noted during the period of the test, but these were very small, seldom varying more than 1 percent from the initial moisture content.

Lot 1, representative of normal air-dried seed and containing 9.59 percent moisture at the time of storage, showed no appreciable decrease in germination until June 1933, 19 months after storage. After June 1933, germination was more variable, indicating that the seed, though still viable, was weaker and required more nearly optimum conditions to germinate. No appreciable differences were shown in the germination percentages of seed from lot 1 under the three methods of storage.

Sun-dried seed stored in a tin container at an original moisture content of 8.75 percent showed only narrow fluctuations in moisture content and germination throughout the period of storage. On April 24, 1934, approximately 2½ years after storage, the sun-dried seed

[3] SIMPSON, D. M., and STONE, B. M. VIABILITY OF COTTONSEED AS AFFECTED BY FIELD CONDITIONS. Jour. Agr. Research 50:435-447. 1935.

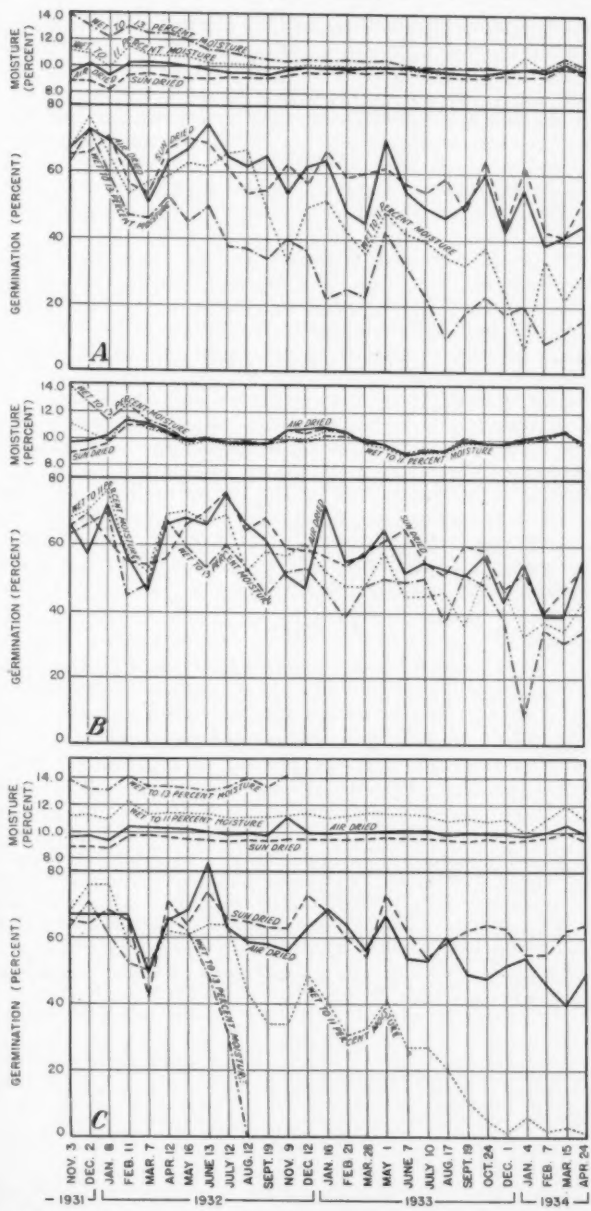

FIGURE 1.—Relation of moisture content to germination of upland cottonseed. *A*, Stored in bins; *B*, stored in bags; *C*, stored in tin containers. Solid lines indicate air-dried seed; broken lines, sun-dried; dotted lines, wet to 11 percent moisture; lines of dots and dashes, wet to 13 percent moisture.

contained 9.38 percent moisture, and 64 percent germinated. At the conclusion of the tests, this lot gave the highest germination percentage obtained from any of the stored seed.

Seed wet to 11.16 percent moisture content and stored in a tin container showed little decrease in viability during the first 8 months of storage, the test made on July 12, 1932, showing 64 percent germination as compared with an original germination of 67 percent. However, the decrease in germination was rapid after July 1932 and on April 24, 1934, at the close of the test, only 1 percent of the seed from this lot germinated.

Seed wet to 13.78 percent moisture and stored in a tin container fluctuated only slightly from this moisture percentage during the period of the test. The germination percentage of these seeds was not lowered by the high moisture content during the first 6 months of storage, but after 6 months it decreased rapidly, and the seeds were all dead 9 months after the beginning of storage.

From the foregoing tests, it is evident that a moisture content in excess of 10 percent is a critical factor in the longevity of stored cottonseed. Reducing the moisture content below 9 percent materially lengthens the time that the seed may be safely stored, provided the method of storage is such as to prevent the reabsorption of moisture from the atmosphere. If the seed contains moisture in excess of that ordinarily induced by atmospheric conditions, open storage providing ventilation reduces the moisture content and improves the storing qualities of the seed.

SUMMARY

Storage experiments with sea-island and upland cottonseed under the humid conditions prevailing at James Island, S. C., showed that in ordinary storage cottonseed deteriorates rapidly after 2 years. A definite relation is indicated between the moisture content of the seed during storage and the rapidity of deterioration. Sea-island seeds, with a moisture content reduced below 8 percent, when stored in tin containers to prevent the rapid reabsorption of moisture, retained their germination percentage with only slight impairment for 4½ years. Upland cottonseed stored under various conditions and containing from 8.75 to 13.78 percent moisture deteriorated rapidly when the moisture in the stored seed remained above 10 percent. Dried seed stored to prevent reabsorption of moisture showed only slight deterioration after 2½ years. Seed containing 13.78 percent moisture and stored to prevent drying were all dead 9 months after the beginning of storage.

A STUDY OF SOME UNPRODUCTIVE SPORTS OF THE MONTMORENCY CHERRY[1]

By V. R. GARDNER[2]
Director, Michigan Agricultural Experiment Station

INTRODUCTION

The literature of fruit growing contains a number of references to barren or semibarren strains. The fact that more attention has been devoted to their occurrence in citrus than in other classes of fruits has led to the rather general assumption that they appear rarely or at least very infrequently in the common deciduous fruit groups, and that they are of relatively small economic importance. Indeed, the existence of truly unproductive variations that can be and are perpetuated as strains has been denied by some. There is, nevertheless, evidence that such strains have appeared and have been propagated, either intentionally or unintentionally, in a number of fruits. According to Carrière (*2*),[3] such a sport of the Frankental grape was known as early as 1866, and Powell (*1*) described an instance of the deterioration of a commercial stock of the Fay Prolific currant through the appearance and propagation of unproductive strains. More recently attention has been called to the appearance of similar barren or semibarren strains in the Bartlett pear (*8*), the Downing gooseberry (*12*), the Montmorency cherry (*5*), and in several varieties of the sweet cherry (*4, 6*). Though there seem to be few recorded instances of the reverse type of sporting, where a barren or semibarren form gives rise to a productive type, such instances are not unknown. Thus, a double-flowered and barren form of the horse-chestnut has given rise to a single-flowered branch that sets and matures seed (*7*), and a nonproductive variety of the Alpine currant (*Ribes alpinum sterile*) has yielded a productive form through bud mutation (*3*).

Apparently, in most of the unproductive strains of *Citrus*, lack of fruitfulness is associated with a failure of the blossoms to set fruit, for they are described as blossoming profusely (*9, 10, 11*). Most of these unproductive *Citrus* strains are said to be characterized by an exceptionally strong vegetative growth. The barren sweet cherry sports that have been described likewise blossom freely, though a large portion of their flowers are undersized and more or less defective in appearance (*6*), and they set little fruit. Little information is available as to the factors or characteristics that are associated with a lack of productivity in the other barren or semibarren sports that have been described.

[1] Received for publication Nov. 20, 1934; issued May, 1935. Journal Article No. 197 (n. s.) from the Michigan Agricultural Experiment Station.

[2] Several members of the staff of the horticultural section of the Michigan Experiment Station from time to time have collected records of fruit setting or frost injury on some of the variants herein described. Thanks are especially due Dr. George F. Gray for preparing the thousands of sections of flower buds, flowers, and developing fruits that were used in this study. The photograph from which figure 2 was reproduced was supplied by R. E. Gibson, of South Haven, Mich.

[3] Reference is made by number (italic) to Literature Cited, p. 478.

OBJECT OF THE STUDY

Field observation in a large number of commercial Montmorency cherry orchards in Michigan during recent years, coupled with a considerable number of individual tree yield records, has convinced the writer that the appearance of unproductive bud sports [4] is of much more common occurrence in the Montmorency variety of the sour cherry (*Prunus cerasus* L.) than has generally been suspected, and that there has been a consequent deterioration in crop yields of considerable magnitude. To ascertain the real status of the problem, a somewhat careful study was made of a number of these unproductive sports that for one reason or another had attracted attention. Descriptions of some of the more distinctive of these forms follow.

PRESENTATION OF DATA

LOW PRODUCTIVITY ASSOCIATED WITH LIMITED FLOWER-BUD FORMATION

Station Selection 194

Since 1929 the Michigan Agricultural Experiment Station has had under observation, in a commercial planting of Montmorency cherries near Fennville, Mich., a large tree that has been cataloged and propagated as selection 194. When first described it had a trunk diameter of about 8 inches, being one of the largest trees in the orchard. About two-thirds of the top of this tree seems to be entirely normal for Montmorency, producing year after year medium-sized crops of normal-appearing fruit. The other third, comprising one large scaffold limb (fully 3 inches in diameter) that is more or less outgrowing the remainder of the tree, has, in each of the 5 years it has been under close observation, borne very lightly—the yield varying from an estimated one-tenth to an estimated one-quarter of a crop. The flowers on the semibarren limb appear normal in every respect and the fruits which it matures cannot be distinguished from those borne by the remainder of the tree. On the other hand, this limb bears distinctly fewer flowers, relatively, than the remainder of the tree or than is normal for trees of the Montmorency variety, and practically all its fruits are from flowers developing from buds on shoots. The spurs of this branch are practically without visible lateral flower buds, while those of the remainder of the tree each year develop a considerable, if not the usual, number of such flower buds. The failure of the spurs of this limb sport to form a normal number of lateral flower buds is well brought out in table 1 and figure 1. Over half of the spurs are entirely barren and most of those that form flower buds develop only a very small number. These wholly barren or lightly productive spurs are scattered evenly and indiscriminately over the bearing surface of the limb. The few flower buds that are produced by the spurs of the barren sport, however, are apparently as good individually as those produced elsewhere in the tree or on other trees. Why the spurs on this particular branch should fail to form flower buds freely is somewhat dif-

[4] The term "sport" is used in this paper to refer to a whole-tree or limb variant that has been under observation for a number of years so that the permanence of its deviation from type in the orchard or in the tree is established. In most of the instances cited the variant and the accompanying parent or normal form have been propagated vegetatively. In some instances a number of the daughter trees have reached bearing age and the existence of barren or semibarren strains of bud-sport origin has been definitely established. In others the daughter trees have not been under observation long enough for a comparison to be made of their behavior with that of the parent or normal forms.

ficult to understand, for they have as many and as large leaves as the normally productive spurs. Attention is called to the fact that the so-called "normal" part of this unusual tree produces a larger percentage of barren spurs and spurs that average fewer lateral flower buds than is characteristic of other Montmorency trees of the same age in the same orchard.

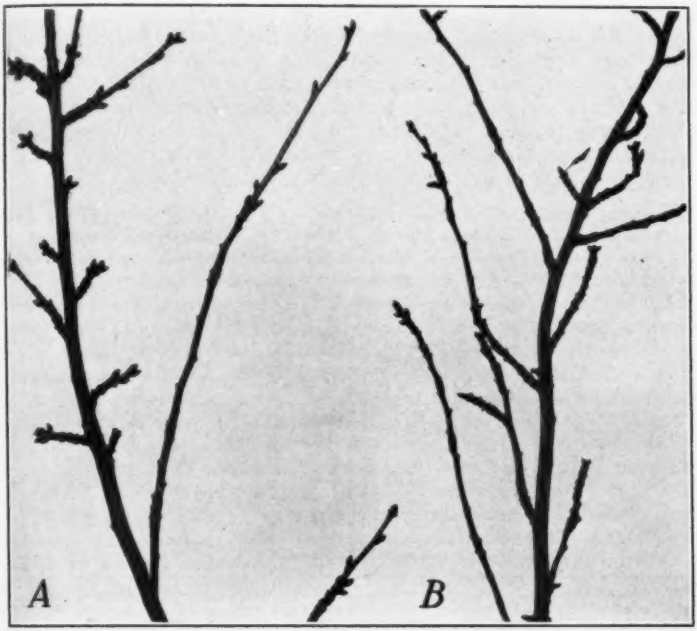

FIGURE 1.—*A*, A fruiting limb of the "normal" part of a tree on which selection 194 appeared as a bud sport; *B*, a typical limb of selection 194. Note the almost complete absence of flower buds on spurs of *B*.

TABLE 1.—*Flower buds on random samples of spurs from station selection 194, from the "normal" part of the same tree, and from other typical Montmorency trees, 1933*

Flower buds per spur (number)	A typical Montmorency tree (check)		Total for random samples of 190 trees in a typical Montmorency orchard		Normal part of tree having limb sport		Limb sport Selection 194	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
0	1	2	418	5	4	9	31	53
1	2	5	370	4	11	23	10	17
2	3	8	810	10	5	11	11	19
3	8	21	1,413	17	5	11	6	10
4	13	33	2,213	27	11	23	0	0
5	10	26	2,106	25	7	15	0	0
6	2	5	820	10	4	9	0	0
7	0	0	117	1	0	0	0	0
8	0	0	13	0	0	0	0	0
Total	39		8,280		47		58	
Mean	3.7		3.7		3.0		.9	

Though the lack of productivity of this bud sport (selection 194) is plainly due primarily to the partial failure of its spurs to form flower buds, its flower buds show a somewhat greater susceptibility to frost injury than those of the normal part of the tree (in the spring of 1933 the percentages killed were 34 and 17, respectively).

Other Instances

After the discovery of the semibarren limb sport, described above, watch was kept for other sports of a similar type. Altogether, seven have been found in widely separated parts of Michigan. They differ more or less from one another, ranging from almost completely barren forms to what may be termed simply light producers. Brief descriptions of these sports are presented herewith and data on the number of fruit buds per spur are given in table 2.

TABLE 2.—*Frequency distribution of numbers of flower buds per spur on certain semibarren limb sports and on the "normal" [1] portions of the same trees*

Buds per spur (number)	Number of spurs of selection no.—											
	625, sport	626, normal	629, sport	630, normal	693, sport	694, normal	695, sport	696, normal	700, sport	701, normal	702, normal	703, sport
0	162	12	69	0	178	6	72	22	72	18	25	49
1	6	5	43	1	3	3	7	9	10	10	15	16
2	0	14	49	5	0	8	9	4	11	12	13	14
3	1	14	77	14	0	4	4	14	15	9	11	10
4	0	15	74	31	0	16	3	13	7	20	5	0
5	0	11	79	35	0	13	0	4	5	20	4	0
6	0	6	25	17	0	7	0	0	0	9	0	0
7	0	3	2	0	0	1	0	0	0	1	0	0
Total	171	80	418	103	181	58	95	66	120	99	73	89
Mean	.05	3.1	2.9	4.4	.02	3.6	.5	2.0	1.1	3.0	1.6	.8

[1] What is here designated as "normal" is, more accurately, the nonsporting portion of the tree. In reality it is in some instances, something intermediate between the true normal condition for the variety and that found on the sporting limb.

Selection 693 is a limb sport discovered in 1933 in the orchard of W. McManeth, north of Traverse City. Like selection 194, it is a large scaffold limb in a tree that is 7 to 8 inches in diameter. It is, however, almost completely barren, for flower buds are formed on less than 2 percent of its spurs, though all of them have the usual amount of foliage. The few blossoms and fruits that it bears seem to be entirely normal for the Montmorency variety.

Selection 625, another limb sport, was found in 1933 in the orchard of J. Flack in the Grand Traverse district. It resembles selection 693 more closely than it does selection 194 in that almost all of its spurs are barren. This branch is about 2 inches in diameter and originated as a limb sport in the top of a tree that must have been at least 8 or 10 years old at the time the sport appeared. Its position in the tree is such as to lead to the belief that the terminal bud on an oblique upright branch suddenly sported in this way, for the lateral branches on this branch up to a certain point are all normal in spur growth and productivity, while those that originate above that point bear spurs of the type just described. The limb sports 194 and 693, on the other hand, developed from lateral buds.

The limb sport cataloged as selection 700, discovered in an old tree in the orchard of D. H. Metzger, Traverse City, in 1933, closely resembles no. 194, in that it constitutes a main scaffold limb (4 to 5 inches in diameter, in this instance) and that it is a semibarren form rather than an almost completely barren form like nos. 625 and 693. Two-thirds of its spurs are without flower buds, and the remainder form a smaller number than do the spurs on the main, normal part of the tree (table 2). The normal part of the tree is very productive. Counts made shortly after a period of severe cold in February 1934, when temperatures as low as −30° F. were recorded in the neighborhood of this orchard, showed that 49 percent of the flower buds of this limb sport had been killed, whereas only 12 percent of those on the normally productive part of the tree (no. 701) had been killed. Similar differences were not found between the other barren or semibarren limb sports described in this group and their normal checks. The low productivity of this particular limb sport is, therefore, to be attributed at least in part to the susceptibility of its flower buds to winter injury.

The limb sport cataloged as selection 629 was first noticed in 1930. It was found in the very top of a tree, then about 25 years old, in the experiment station orchard at East Lansing, the branch in question being about one-half inch in diameter. The tree as a whole has been normally productive, but each year this branch produces a very light crop. Reference to table 2 shows that, though its spurs averaged nearly 3 flower buds each, this is only about two-thirds the number produced by the spurs on the normal part of the tree. Thirty-eight percent of its spurs had less than 3 buds each, while only about 6 percent of the spurs of selection 630 had less than 3 each. The semibarren condition of this particular limb sport is due in part to the fact that a much lower percentage of its blossoms set fruit than do those on the main part of the tree. Further reference to this characteristic will be made later.

The tree in which the forms cataloged as selections 702 and 703 were found is located in the orchard of John Stanek, at Traverse City. One part of this tree, the main portion (selection 702), is moderately productive and matures its fruit at the usual ripening season for Montmorency. Its fruits appear normal in every respect. Reference to table 2 shows, however, that its fruit spurs averaged only 1.6 flower buds each—half the number characteristic of Montmorency. Especially significant is the fact that a third of the spurs were entirely without flower buds. Though this tree is perhaps a little less favorably located with respect to soil than most of the others in the same orchard, the trees immediately surrounding it had spurs with the usual number of flower buds. All have had uniformly good care, and the small number of buds per spur cannot be attributed to lack of soil fertility or poor foliage. The evidence indicates that what is here called the "normal" part of the tree is intermediate between a fully productive condition and low productivity.

A limb sport in this same tree, cataloged as selection 703, is light-yielding and matures its fruit from 10 days to 2 weeks later than normal. Over half of its spurs are barren, while the remainder have only a few flower buds (table 2). The barren spurs on both parts of this tree—i. e., on the parts cataloged as selections 702 and 703—are

distributed more or less evenly or indiscriminately over the entire bearing surface.

A tree located in the orchard of J. Flack on the Old Mission Peninsula north of Traverse City, is interesting in that it apparently represents a condition intermediate between the one furnishing selections 702 and 703 and that furnishing selections 625 and 626. In this instance the tree is relatively young (set in 1925) and very vigorous. A third of the spurs on its "normal" part (cataloged as selection 696), however, in spite of its excellent care, vigorous condition, healthy foliage, and the barely moderate crop that it bore in 1933, formed no flower buds for 1934, though the spurs that did form buds developed a normal number. Three-fourths of the spurs on its large, semibarren limb sport (cataloged as selection 695) failed to form flower buds, and those that did develop them differentiated only a little more than half the number characteristic of the variety (table 2). Thus, the moderately productive main part of the tree (no. 696) is comparable to selection 702, while its semibarren limb sport (no. 695) is intermediate in type between selections 703 and 693. The distribution of the barren spurs on the smaller limbs of both no. 696 and its limb sport, no. 695, roughly resembled that of color striping in certain sectorial chimeras.

Another limb sport of this same type, i. e., one whose fruit spurs were barren or nearly so, was discovered in 1931 in the orchard of George Wheeler, near Shelby. It was cataloged as selection 597 and buds were obtained for propagation, but exact counts were not made of the number of flower buds per spur.

It is evident from the foregoing descriptions that these Montmorency sports, characterized by fruit spurs that develop few or no flower buds, constitute a series. Some like no. 693, are almost completely barren; others, like nos. 696 and 626, fall only a little short of being moderately productive. Between the two extremes may be found almost any intermediate form.

BARRENNESS ASSOCIATED WITH DEVELOPMENT OF LEAF BUDS IN PLACE OF FLOWER BUDS

In 1932 Drain (*5*) described a barren limb sport of the Montmorency, then being propagated at the Michigan station as selection 152 (fig. 2), in the following terms:

> This is a sector of an old Montmorency tree growing in the McCrasslin orchard of the late Amos Tucker, of Bravo, Mich., and has been observed for a number of years. The off-type sector has outgrown the rest of the tree. Its foliage is dark green in color and very dense, except on young, rapidly growing shoots. Spurs are produced in profusion, but very few blossoms. * * * The few fruits produced on the vegetative portion of the tree appear normal for Montmorency.

Closer examination of the parent tree shows that the normal portion possesses the spur-bearing habit in a marked degree—i. e., very few of the lateral buds on the shoots, even the very short shoots differentiate flower parts—and consequently practically the entire crop is spur-borne. Similarly, the lateral buds on the shoots of the barren limb sport are exclusively, or almost exclusively, leaf buds. On the other hand, while the spurs on the normal portion of the tree develop the usual number of flower buds and regularly set and mature a large crop of fruit, the buds that develop in the axils of the spur leaves on the barren limb sport are leaf buds.

Sections made through these buds collected at successive stages throughout the summer, fall, and winter show them to be practically identical in structure with the terminal leaf buds on the same spurs or the terminal buds of the spurs on the normal part of the tree. These lateral leaf buds are smaller and more pointed than the flower buds occupying a similar position on the spurs of the normal part of

FIGURE 2.—Tree in which selection 152 originated as a limb sport (limb in foreground, lettered *BM*). Note its tendency to outgrow the remainder of the tree and the density of its foliage, as compared with that on the normal limb at the left.

the tree (fig. 3). In the spring when growth starts, these leaf buds open, and each one produces a small rosette of leaves, just like the normal terminal bud of the spur, though, owing to competition and the consequent crowding, a considerable percentage of the growing points die and are abscised. Nevertheless, some of them are able to survive, the result being the gradual development of much-branched

spurs. This gives the older portions of the tree the appearance of possessing a very compact, dense type of growth (fig. 2). Occasionally, one of the lateral buds on the spurs of this limb sport matures fruit, but the percentage of such buds is less than 1. Sections of buds from this limb sport collected at intervals throughout the year show that in those few instances where flower buds are formed, differentiation takes place at the usual season, flower development is normal, and the flowers open when the rest of the tree is in blossom. Trees of bearing age propagated from this limb sport reproduce its characteristics faithfully.

FIG. 3.—Representative spurs of selection 152 are shown in *A* and from the normal portion of the same tree at *B*. Note the difference in the size and shape of their lateral buds. The lateral buds of the limb sport no. 152 do not differentiate flower parts.

In the summer of 1933 two other limb sports, almost identical in appearance with selection 152, were found in orchards of different ages in the vicinity of Traverse City, and two others were found in an orchard about 10 years old near Eau Claire. The Traverse City sports are now being propagated as selections 615 and 627, and the Eau Claire variants as selections 656 and 658. In the Eau Claire orchard yielding selections 656 and 658 there is a whole-tree variant of the same character (cataloged as selection 654), which has in turn produced several small branches whose spurs show a complete return to the normally productive condition.

Still another limb sport of this same type (cataloged and propagated as selection 608) should be recorded in this connection. To the casual observer it appears practically identical with nos. 152, 615, 627, etc. It differs, however, in that though some of its few flower buds open at the same time as those on the normal part of the tree (selection 609), others are only half or a quarter grown, and their blossoming season is prolonged for a full month beyond that which characterizes the parent variety. Numerous sections of lateral spur buds of this limb sport collected at regular intervals indicate that, though

very few ever differentiate flower primordia, and though a considerable percentage of the few that do, differentiate them at the usual time, in some buds differentiation occurs a month or 6 weeks later than normal. This is well brought out in figure 4. In this particular sport, it is the buds whose flower primordia differentiation is "post-season" that develop slowly and open late the following spring.

LIGHT PRODUCTION ASSOCIATED WITH SUSCEPTIBILITY OF FLOWER BUDS TO KILLING BY LOW MIDWINTER TEMPERATURES

Winter-killing of flower buds has always been recognized as more or less of a limiting factor in sour cherry production, as it is with other

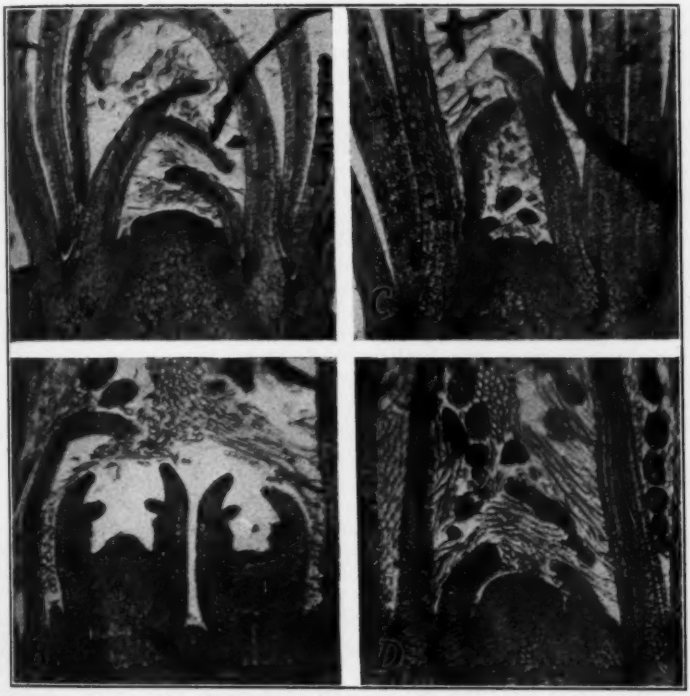

FIGURE 4.—*A* and *B*: Sections through the growing points of representative lateral spur buds of a normal Montmorency cherry tree collected July 14 and August 14, respectively, showing early and well-advanced stages of flower-bud differentiation; *C* and *D*, corresponding sections through the growing points of the few lateral spur buds on its semibarren limb sport (selection 608) that differentiate flower parts. By August 14 the flower buds reach about the same stage of development attained by those of its parent tree a month earlier (× 65).

deciduous fruits, though observation indicates that it is relatively of much less importance than the killing of opening buds by spring frost. In the effort to ascertain the causes of the light cropping of many cherry trees it was decided to look for evidence of bud sports that might be susceptible to low winter temperature. The data on several of the more striking cases follow.

Selections 262 and 263

In the spring of 1932 an old Montmorency tree was found in the orchard of Clayton Riley, near Mears, which had one limb, about 2 inches in diameter, carrying only a third or half a crop of blossoms, while the remainder of the tree was carrying a normal crop. Many of the flower buds on the light-blossoming limb had not opened and many of those that had opened were producing only 1 or 2, instead of 3 or 4, blossoms. Examination showed that the individual flower rudiments in these buds were dead, presumably from midwinter freezing. The light-blossoming limb in this tree was cataloged as selection 262, and the normal, main part of the tree as selection 263. Limb 262 matured a very light crop in 1932, while the rest of the tree produced a heavy crop. The winter of 1932–33 was one of ordinary temperatures and there was practically no winter-killing of flower buds on either part of this tree. However, there was considerable frost injury in the spring of 1933. Count of a random sample of blossoms showed that 48 percent of those on limb sport 262 had been killed, and 53 percent of those on selection 263. Both parts matured a medium-sized crop of fruit in the summer of 1933. In February 1934, there were unusually low temperatures. Examination of flower buds collected March 10 showed winter-killing of 17 percent of the individual flowers in selection 263 and 47 percent of those in its limb sport (no. 262). In July 1934, limb sport 262 matured a medium-sized crop, while the normal part of the tree matured a heavy crop—and this in spite of the fact that counts made at the blossoming and harvesting seasons showed that fruit setting was substantially higher on the limb sport than on the normal part of the tree.

Selections 264 and 265

About 200 yards from the tree in which selections 262 and 263 were found is another, several years younger, that in 1932 similarly showed rather marked differences from limb to limb in the percentages of flower buds that had been winter-killed, followed by corresponding differences in yield. The limb showing the largest amount of winter-killing of flower buds and lighter yield was cataloged as selection 264; the remainder of the tree as selection 265. As in selections 262 and 263, there was no killing of flower buds during the winter of 1932–33. Both parts of the tree showed the same amount of frost injury to blossoms (28 percent) in the spring of 1933, and both parts matured a good crop the following July. Following the low temperatures of February 1934, examination showed that 75 percent of the blossom buds on limb no. 264 were killed, while only 53 percent of those on no. 265 were killed. This at first does not seem to be a great difference, but when translated into terms of survival, it is a difference of 2 to 1 and corresponds rather closely with the subsequent (1934) yields of the 2 portions of the tree.

Selections 481, 482, and 482A

A tree of the Montmorency variety with a limb sport of peculiar growth habit, producing small-sized, early maturing fruits, was found in an old orchard belonging to George Andrews, near Shelby. It has been under observation since 1929. The east side of this tree

(cataloged and propagated as selection 481), which constitutes about a third of the entire top, in vegetative, flower, and fruit characters appears entirely normal for Montmorency. The remainder of the tree (propagated as selection 482) is somewhat more vigorous and upright in growth, with thicker shoots. Its internode length averages about 1½ inches, as compared with 2 inches for no. 481; its flower clusters average 2.4 flowers each, as compared with 3 for no. 481; its fruits in 1933 averaged 2.68 g in weight as compared with 3.44 g for no. 481. They mature about 10 days earlier than the normal Montmorency cherries and are somewhat milder in flavor.

In some seasons both parts of this tree have been equally productive; in others the aberrant sector, no. 482, produced a relatively lighter crop than the normal sector, no. 481. In the spring of 1933 it was noted that not only did many of the flower buds on sector 482 fail to open, but on 1 of its branches (about 1½ inches in diameter) very few were starting to open, while practically all were opening on the normal sector, no. 481. Examination showed that the buds failing to open had been winter-killed. Here then, were three parts of a tree presenting markedly different amounts of winter-killing of flower buds. The limb showing the most serious winter-killing and growing out from sector 482, was propagated as selection 482A. Some frost injury occurred in this orchard a week or 10 days before the full-bloom stage, and when the blossom buds were in that stage of development, those on all three parts of the tree suffered about the same amount of injury, 25 to 30 percent being killed. Furthermore, approximately the same percentage of the blossoms that survived winter and frost injury on the three parts of the tree set and matured fruit. The crops borne corresponded closely to the amounts of winter-killing of the flower buds—being heavy, moderate to light, and very light on sector 481, 482, and 482A, respectively.

Following the low temperatures of February 1934, counts were made of large random samples of the flower buds from the three sectors of this tree. The percentages killed were 12.5, 42.5, and 67.7 on parts 481, 482, and 482A, respectively. The killing on sector 481 was not severe enough to reduce the crop appreciably; indeed, that sector actually matured a very heavy crop. Killing on sector 482 was enough to reduce the crop considerably, and that on limb 482A was enough to reduce it drastically. The 1934 yields actually produced were in line with what one would expect from the amounts of winter-killing of flower buds.

Selection 159

The whole-tree variant catalog as selection 159 is one of a large block of trees planted in 1905 near Sodus, Mich. It is thrifty, vigorous, and large enough to average 150 to 200 pounds of fruit per year. In no season during the 5 years that it has been under the author's observation has it borne more than 25 pounds of fruit, though trees surrounding it have yielded heavily. The owner states that it has always been either light-cropping or semibarren.

In March 1933, examination of flower buds from this tree showed that a large percentage were dead (exact number not determined), though there had been practically no killing of those on surrounding trees. This, coupled with the fact that examination in early November 1932 showed no dead flower buds and that the winter of 1932–33

had been comparatively mild, led to the belief that flower buds of this tree are especially susceptible to injury from winter cold. There was some spring frost injury in this orchard in 1933, averaging 30 percent on the trees surrounding selection 159 and 71 percent on selection 159. Following the severe winter of 1933–34 this tree showed 59 percent winter-killing of flower buds, while surrounding

FIGURE 5.—A small reverting limb that is normally productive growing out as a lateral from a larger branch in semibarren selection 159.

trees averaged only 21 percent. There was no spring frost injury in this orchard in 1934.

It is evident from these data that the flower buds of selection 159 are markedly more susceptible to injury from cold, both in midwinter when they are dormant and in late April when they are about ready to open and frost becomes a limiting factor, than are most Montmorency cherry buds. Without question, the low productivity of this tree is in considerable part due to the tenderness of its flower buds, though it is likewise due in part to the poor setting of its blos-

soms, a matter that will be discussed later. It is significant that two small branches, perhaps half an inch in diameter, near the top of this old tree have shown a full return to normal productivity (figure 5). No records have been obtained on blossom-bud killing or fruit setting on these branches, but presumably they are as hardy and the flowers set fruit as well as those on other Montmorency trees in this orchard.

Selection 700

As stated earlier (p. 461), the limb sport cataloged as no. 700 showed winter-killing of flower buds amounting to 49 percent following the severe winter of 1933–34, while the buds on the normal part of the tree (no. 701) showed only 12 percent killing. Here, again, susceptibility to injury from cold furnishes only part of the explanation of the near-barren condition of the sport. It is, nevertheless, a factor of considerable importance.

LOW YIELDS DUE TO DELAYED WINTER-KILLING OF FLOWER BUDS

In some instances the flower buds of the Montmorency cherry may be very resistant to low temperatures throughout the winter while they are in a dormant condition, only to become very sensitive as growth is resumed in early spring. This, however, is associated with very early spring freezing and probably is to be regarded as a delayed form of winter-killing rather than killing from spring frosts which come later.

Selections 698 and 699

In the summer of 1933 a limb sport was found in an old Montmorency tree in the orchard of D. H. Metzger, at Traverse City, which was nearly barren. The main part of the tree was normally productive and carried a heavy crop. The twig growth, shoots, spurs, foliage, and fruits of the nearly barren branch appeared to be entirely normal, but the crop was less than a tenth of what it should have been. Later examination showed that the spurs on this part of the tree produced the usual number of flower buds, and sections of these flower buds revealed no peculiarities of structure or development. Samples collected from both the sporting branch and the normally productive part of the tree on March 23, 1934, while they were still in a dormant condition, showed that 21 percent of the individual flower buds of the nearly barren limb sport had been killed by the unusually low temperatures of the preceding winter, while only 5 percent of those on the productive part of the tree had been killed. This was a significant difference but not enough to account for the difference in productivity of the two parts of the tree. However, when a check was made on May 14, 1934, several days before the full-bloom stage, it was found that in 80 percent of the flower buds of the semibarren limb sport all of the individual flower buds had been killed, while the corresponding percentage for the normally productive part of the tree was 11. Furthermore, those buds on the limb sport from which flowers had emerged were producing only 1 or at most 2 each, instead of the usual 2 to 4. Total delayed winter-killing of individual flowers on this limb sport, therefore, amounted to at least 90 percent of those that had survived midwinter killing, whereas not more than 20 percent had succumbed on the main, normal part of the tree. However, as the season advanced, the developing

flower buds of this limb sport showed a resistance to low temperatures equal to that of the normal part of the tree, for a light frost on the morning of May 12 destroyed a slightly smaller percentage of the buds on this limb than on selection 699 or on surrounding trees. Examination showed that the buds on this semibarren limb sport paralleled in their differentiation and development those on its normal parent tree, their tender early spring condition not being due to greater or lesser advancement.

Selections 680 and 681

A limb sport designated as selection 680, discovered in another orchard in the Traverse City section in 1933, closely resembles the semibarren no. 698, except that its blossoming season is about a week later and its maturing season about 2 weeks later than its parent form (No. 681). Examination of large random samples of its flower buds on March 23, 1934, failed to reveal a single dead one on the normally productive part of the parent tree. However, 76 percent of the flower buds of the semibarren limb sport succumbed to the delayed winter-killing that occurred later, while the corresponding percentage for the productive portion of the tree was 23. In this instance the owner of the orchard had observed this tree for many years and stated that the limb sport had never borne a full crop, while the remainder of the tree had been consistently productive.

Selection 697

A whole-tree variant of the same type as limb sports 680 and 698 was found in still another orchard near Traverse City in 1933. It was healthy, vigorous, well cared for, and of a size to produce a hundred-pound crop in 1933. Actually, it yielded about 3 pounds. It differentiates the usual number of flower buds, and examination revealed no peculiarities in their structure. Ninety-five percent of its individual flower buds survived the severe winter of 1933–34 (examination of Mar. 23, 1934)—about the same percentage that survived on surrounding normally productive trees. A check made May 14, however, showed that in 71 percent of its flower buds all of the individual flowers had been killed before opening and apparently an equal percentage in the remainder that did open. The presumption is that this tree was accidentally propagated from a limb sport similar to selection 698.

Low yields due to susceptibility of buds or flowers to frost

In the discussion of selection 159 (p. 457), attention was called to the fact that not only are the dormant flower buds of this tree markedly susceptible to low temperatures, but its opening flower buds are likewise more susceptible to frost injury than those of surrounding normal trees. The percentage of flower buds on this tree killed by frost in the spring of 1933 was 71, while the corresponding figure for a composite sample from the surrounding trees was 30.

In early June 1932 the attention of the writer was called to two adjacent Montmorency cherry trees in an orchard of several hundred trees of that variety on the farm of Abel Teichman, at Eau Claire. Each of the two trees had a height of about 17 feet and an equal or slightly greater spread. Destructive frosts had occurred in late April,

and there had been considerable frost injury in this particular orchard. Examination showed clearly that both of the two trees had blossomed heavily, but that one had suffered only slight injury to its blossoms while the other had suffered extensively. At harvest 185½ pounds of fruit was picked from one tree (designated as selection 511), while the other (selection 512) yielded only 7¼ pounds. Both trees made a reasonable amount of new growth in 1932, though selection 512

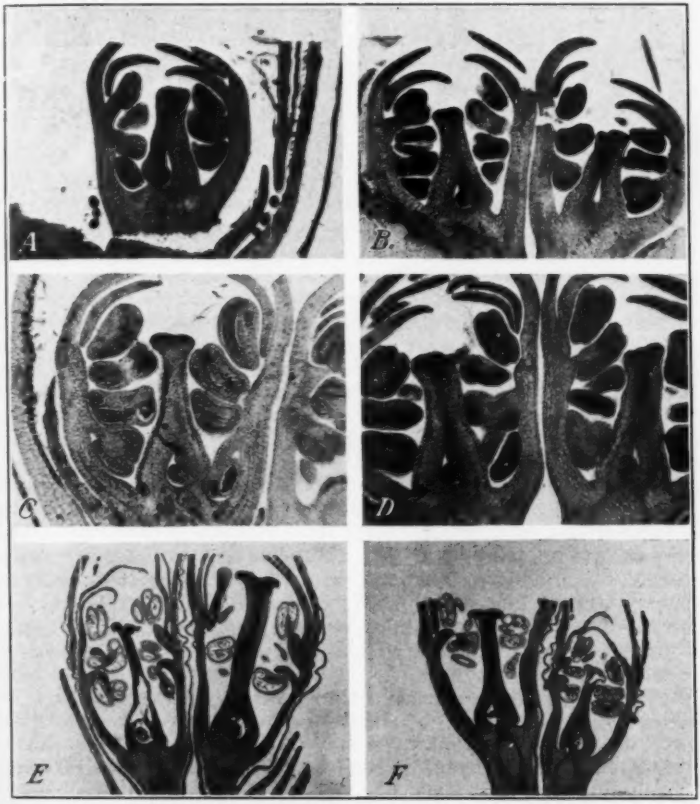

FIGURE 6.—*A*, *C*, and *E*: Photomicrographs showing the November 9, April 5, and April 29 stages of representative flower buds of selection 511, a form whose blossom buds are resistant to spring frost injury; *B*, *D*, and *F* photomicrographs showing corresponding stages of selection 512, an adjoining tree whose blossom buds are very susceptible to spring frost injury. Both of the pistils in *F* and one of those in *E* were killed by a frost that occurred 3 days before the flowers were collected for sectioning. *A*, *B*, *C*, and *D* × 33 *E* and *F* × 7.

came through the season in better condition and with a much larger number of fruit buds because of the light crop that it carried. On April 25 and 26, 1933, low temperatures again occurred in southwestern Michigan, and there was more or less frost injury to opening flower buds in the Eau Claire district.

Counts made April 29 showed that 87 percent of the individual flower buds on tree 512 had been killed, while only 27 percent had been

killed on tree 511. The frost-resistant tree yielded 142 pounds of fruit in 1933, while the frost-susceptible tree yielded only 77 pounds. This difference in yield was much smaller than would be expected from the difference in frost injury to the blossom buds, principally because of the poorer budding (i. e., the development of smaller numbers of flower buds) of the frost-resistant tree occasioned by its heavy cropping in 1932. Sections of random samples of the flower buds from these two trees collected in early November 1932, March 30, 1933, and of pistils collected at the time of the frost (fig. 6) showed no differences in size at any stage or in degree or rate of differentiation of flower parts. The flowers of both were at apparently identical stages of development when the injurious frosts occurred, thus indicating that the variations in hardiness could not be associated with anatomical differences.

Two other whole-tree variants characterized by extreme susceptibility of their flower buds to spring frost may be mentioned here. Both are in the Crowley orchard about 15 miles north of Traverse City. Though the site of the orchard is one where considerable frost injury is to be expected, the orchard as a whole has been moderately productive, while these two trees have usually borne light crops. Flower buds are formed freely by both trees, and the fact that they suffered little injury from temperatures ranging from −20° to −25° F. in February 1934, indicates that they are resistant to cold while in a dormant condition. However, after frosts occurring from May 10 to 14, not a single live flower bud could be found on tree 689, while the percentage of flower-killing of a large composite sample from the four surrounding trees was 10. The other tree, no. 690, had 94 percent of its flower buds killed, while the four bordering trees had 11. Obviously, these are instances of extreme susceptibility to frost. The presumption is that all of these whole-tree variants are in reality bud sports, having been propagated from unrecognized limb variants of this kind. That such variants actually occur as limb sports is illustrated by station selection 602, a light-yielding limb in an 8- to 10-year-old tree in the orchard of D. H. Metzger, near Traverse City. This tree has been under the author's observation for several years. Records show that its low productivity (ranging from about a third to a half that of the normal part of the tree) is not due either to a noticeable susceptibility of its dormant flower buds to low midwinter temperatures or of its swelling flower buds to the delayed or late type of winter-killing. On the other hand, its flower buds are relatively very susceptible to killing by late spring frosts. Thus, a series of frosts occurring between May 10 and May 14 in 1934, which killed 27 percent of the blossom buds on the normal part of the tree (selection 601) and about the same percentage on surrounding trees, destroyed 72 percent of the flower buds on this limb sport.

LOW YIELDS DUE TO POOR SETTING OF FRUIT

Earlier in the paper (p. 457) attention was called to the fact that in the case of some of the barren or nearly barren citrus fruits and sweet cherries that have been described, the failure to produce fruit was associated either with anatomically defective flowers or with the inability of apparently normal flowers to set fruit. A number of barren and light-producing forms of the Montmorency cherry due to the latter factor have been encountered in this study.

Selection 676

In the summer of 1933 in the orchard of F. E. Broesch at Traverse City a tree was found about two-thirds of which was bearing a normal crop of fruit. One large limb, in vegetative characters indistinguishable from the rest of the tree, was almost barren, and the few fruits that it produced were of only about two-thirds the usual Montmorency size. The flower buds on this limb (selection 676) were examined from time to time and found to be differentiating and developing their parts in the usual manner. In the spring of 1934 this limb produced a very heavy crop of blossoms, which, however, were only about two-thirds as large as those on the normal part of the tree. Otherwise, they appeared entirely normal. There was no frost injury to the blossoms on this tree in 1934. Fruit setting on this limb, as determined from a large random sample of flowers, amounted to only 0.7 percent, while that on the remainder of the tree was 12 percent. At harvest time in 1934 the tree presented essentially the same picture that it had in 1933.

Selections 634, 635, and 636

In June 1933 in one of the so-called "Corporation" orchards at South Haven, Mich., a tree was noted in which one sector was bearing a heavy crop, another sector a very light crop, and a third sector was completely barren. The first sector, which constituted perhaps a third of the top, yielded 16¼ pounds of fruit; the second sector, which constituted nearly two-thirds of the top, yielded 2¾ pounds; the barren part consisted of a single limb only about 1 inch in diameter. These sectors were cataloged as selections 634, 635, and 636, respectively. Periodical examinations between the harvest season of 1933 and blossoming in 1934 showed that flower-bud differentiation proceeded in a normal manner in all three parts of the tree. There was practically no winter-killing of flower buds on any of the branches, and there was no spring frost injury to the blossoms. All three parts blossomed heavily in 1934, and the blossoms appeared entirely normal. Fruit setting on the three sectors, as determined from large random samples of the blossoms (864, 606, and 1,348), amounted to 42, 33, and 0.5 percent, respectively. Sector 634 yielded 56 pounds, sector 635 yielded 20 pounds, and sector 636 yielded only a few fruits. Here is an instance of three distinct conditions of fruitfulness in a single tree, occasioned by differences in the ability of the flowers to set fruit, comparable in a way to the tree yielding selections 481, 482, and 482A, which presents three different conditions of hardiness of flower buds to winter cold.

Selection 160A

In the spring of 1923 three farmers near Eau Claire, (A. H., Albert, and William Prillwitz) purchased stock for commercial plantings of the Montmorency cherry from a single nursery. When the trees reached bearing age, 2 out of a total of 110 in one orchard proved to be barren, 7 in another, and 20 in the third. The other trees in the three orchards have been normally productive. Though most of these barren trees have been cut down within the past 2 years, several have been retained as curiosities. Field observations indicate that all 29 barren trees were of the same type (designated as selection 160A)—vigorous, thrifty growers, producing round or roundish upright tops

and characterized by rather coarse, stiff, thick shoots and exceptionally large flower buds. The trees bloom profusely each spring. Sections of flower buds collected in late fall and again in early spring, and sections of the pistils just before the opening of the flowers and again at full bloom indicate an entirely normal procedure in the differentiation and development of the several parts of the flower. At blossoming time the trees give every promise of maturing a full crop. The blossoms, however, fail to set fruit, practically all of them having abscised within a week or 10 days after petal fall. Fruit setting, as determined from counts of large random samples of blossoms, has in each of the past 3 years fallen short of 1 percent. Each of these trees may mature 2, 3, or even 100 fruits, which appear to be typical Montmorencies, but the trees may be considered as practically barren.

Selection 365

For 6 or 8 years 1 Montmorency cherry tree growing in one of the Corporation orchards at South Haven, has attracted attention because of its late-blossoming and late-maturing habit. It reaches the full-bloom stage from 3 days to a week later than surrounding trees and it matures its fruit on an average about 2 weeks later than normal. It has never yielded a satisfactory crop for a tree of its size, though in 1930, when there was more or less of a crop failure in the whole orchard on account of spring frost injury, it produced 11¼ pounds, as compared with an average of 7½ pounds for the entire block of 190 trees. In 1931, when the average yield in the orchard was 66 pounds to the tree, this particular tree bore no fruit (due largely to frost injury). In 1932 it produced 21 pounds, as compared with an average for the orchard of 57; in 1933 it bore just 18 cherries, as compared with an average of 22 pounds; and in 1934 it bore 14 pounds, as compared with an average of 109 pounds. Each year it has blossomed profusely, so that yields of at least 50 pounds might reasonably be expected. Records of fruit setting were obtained for each of the 190 trees in this particular block in 1932, 1933, and 1934. For this tree the percentages of the blossoms setting fruit in the 3 years, were 1, practically 0, and slightly less than 2, while the averages for the entire orchard were 10, 13, and 24. Obviously, the tree is not barren to the same extreme degree as limb sports 676, 636, or selection 160A, but it is only slightly more fruitful.

Presumably, both selections 160A and 365, which occurred as whole-tree variants when discovered in the course of this study, originated as chance limb sports such as 676 and 636, and were accidentally propagated.

Selections 516 and 517

In the summer of 1932 it was noted that two parts of a small tree in one of the Corporation orchards at South Haven were bearing very unevenly. Harvest records showed that one side (selection 516) yielded 22 pounds, while the other (selection 517) which had about the same bearing area yielded only 13 pounds. In the spring of 1933 rather severe killing of flower buds by frosts occurred on the nights of April 25 and 26. The percentages killed on the two parts of the tree were 68 and 87, respectively, indicating distinctly greater resistance to frost in selection 516, which had produced the heavier yield

the preceding year. Fruit setting on the two parts of the tree in 1933, as determined from large random samples of uninjured blossoms, amounted to 9 and 1.4 percent, respectively, and the subsequent yields were 1¼ and ¾ pounds. Practically no winter injury to the flower buds of either part was occasioned by the severe winter of 1933–34, and there was no frost injury in the spring of 1934. Fruit setting on the two parts of the tree amounted to 35 and 8 percent,

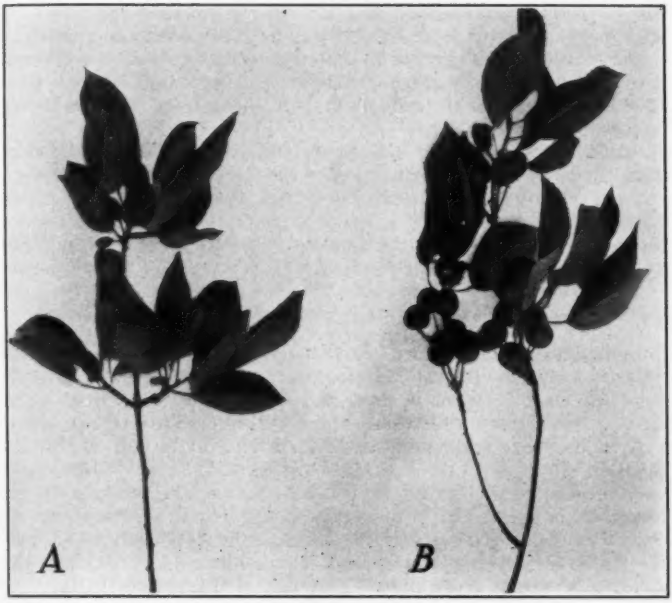

FIGURE 7.—Representative fruiting branches of selections 517 (*A*) and 516 (*B*) crop of 1934, when fruit setting on the two parts of the tree amounted to 8 and 35 percent, respectively.

respectively, and the subsequent yields were 29 and 10 pounds. Figure 7 shows representative fruiting branches from the two halves of the tree.

SELECTIONS 645, 674, 679, AND 686

In the course of this study a considerable number of whole-tree variants, more or less closely resembling limb sport no. 517 or intermediate between it and no. 160A, have been studied. Among these may be mentioned selections 645, 674, 679, and 686.

Selection 645 is a whole-tree variant in the orchard of George Humphrey at Coloma. When first brought to the writer's attention in 1933 it was almost barren, though surrounding trees were heavily loaded. The owner stated that ever since the orchard had reached bearing age, this tree, though blooming profusely each spring, had failed to yield a satisfactory crop. In 1934, fruit setting, as determined from a random sample of 883 flowers, amounted to 2 percent, while records for surrounding normal trees showed a 25-percent set of fruit. The fruit on this tree and its vegetative characters are

unquestionably those of the Montmorency. This is mentioned because of the fact that hand-pollination of a number of the blossoms on this tree with pollen of the Windsor, a sweet cherry variety, yielded a good set of fruit, such as one would expect when using sweet cherry pollen on the blossoms of some variety of the Duke group.

Selection 674 is a whole-tree variant in the orchard of Ralph Rider at Shelby. In 1933 it bore only a very light crop, though surrounding trees of the same age were bearing heavy crops. In the spring of 1934 it blossomed heavily; the blossoms appeared to be normal in every respect, and there was no frost injury in the orchard. Two percent of its blossoms matured fruit while the corresponding percentage on a large composite sample from surrounding trees was 30. The owner was unable to furnish information as to the previous behavior of this tree.

Selections 679 and 686, located in the Gore orchard at Traverse City, could be described in practically the same terms as selection 674, except that the owner had observed for years that these particular trees had been consistently light producers. In 1934, fruit setting, as determined from random samples of 779 and 1,106 flowers, respectively, amounted to 7 and 2 percent.

Other Instances

Though many other records have been obtained of both limb and whole-tree variants in the Montmorency cherry characterized by fruit setting that is below normal and resulting in light bearing or in a more or less barren condition, enough have been cited to show at least that they are not rare. Attention should be called, however, to the fact that a number of the variants that are unproductive primarily because of limited flower bud formation, or susceptibility of flower buds to winter cold or to spring frost, are likewise characterized by poor fruit setting. Thus, selection 159, cited earlier in this paper as having flower buds especially susceptible to winter cold, matured fruits from only 6 percent of its flowers in both 1933 and 1934, while the corresponding set on the four surrounding trees was 21 and 22 percent, respectively, and in 1934 the set on one small "reverted" branch on tree 159 was 23 percent. The percentage of blossoms setting fruit on selection 194, a semibarren limb sport characterized by a very small number of flower buds to the spur, were 29 and 27, respectively, in 1933 and 1934, while the corresponding percentages on the normally productive part of the tree were 35 and 43. Selection 703, a limb variant in the orchard of John Stanek, Traverse City, similarly characterized by fruit spurs bearing few flower buds, matured fruit from 2 percent of its blossoms in 1934, while the corresponding percentage on the more normal part of the tree was 34. Selection 680, a limb sport in the Gore orchard, Traverse City, characterized by delayed winter-killing of its flower buds, matured fruit from only 6 percent of its blossoms in 1934, while the corresponding percentage for the remainder of the tree was 11.

Study of the whole mass of records obtained during the past 5 years relating to various aspects of the problem of low productivity in the Montmorency cherry leads to the belief that to the extent that light cropping is due to bud variation, it results more frequently from poor setting of the blossoms than from any one or even all of

the other factors that have been discussed in this paper. Furthermore, the records show that in a considerable number of instances where low productivity is due primarily to one of these other factors, poor setting is an associated or contributing factor. In a relatively large number of instances poor setting alone seems to be responsible for subnormal yields.

DISCUSSION

The worthlessness, commercially, of strains like selections 152, 159, 680, 697, 160A, and 365, that for one reason or another are practically barren, is obvious. Of far greater importance, because less easily recognized, are the relatively unproductive variants, such as selections 629, 700, 262, 512, and 517. Though each season the grower may note that some trees in his orchard are bearing only light crops, he does not mark them and does not realize that many are consistently and regularly light producers. He believes that they are simply alternating between heavy and light cropping, as is so commonly the case with apples. Indeed, many of these light-producing variants, especially those whose low yields are associated with susceptibility of flower buds or flowers to winter cold or spring frost, may bear normally some seasons, though on the whole they are unproductive. The result is that they are not recognized for what they are and average yields are reduced accordingly.

SUMMARY

A number of sports of the Montmorency cherry that result in yields ranging from substantial reductions from the normal to an almost completely barren condition are described.

They are classified as follows: (1) Those failing to form any flower buds visible to the naked eye in positions where flower buds are usually differentiated; (2) those on which leaf buds occur in positions where flower buds are ordinarily formed; (3) those showing marked susceptibility of flower buds to injury from low temperature while in a dormant condition; (4) those showing marked susceptibility to injury from less severe temperatures while in delayed dormant or early post-dormant condition; (5) those showing marked susceptibility of flower buds or opening flowers to spring frost, and (6) those characterized by poor fruit setting.

All these departures from type occur as limb sports or as whole-tree variants, the latter presumably originating as limb variants.

From a commercial standpoint, unproductive variants in this variety due to poor fruit setting are more important than those due to other factors.

There is a rather marked tendency for variants that are unproductive because of one of these six factors to have their yields reduced still further by one or another of the other factors.

Variants producing light yields are more important commercially than those that are almost barren, because they are less easily recognized.

LITERATURE CITED

(1) Anonymous.
1899. bud variations. Gard. Chron. (3) 25: 129.
(2) Carrière, E. A.
1866. chronique horticole. Rev. Hort. 38: 362.
(3) ——— and André, E.
1891. anomalie présentée par le groseillier stérile. Rev. Hort. 63: 413–414.
(4) Dickson, G. H.
1933. the retrograde sports or mutations in apples. Canad. Hort. 56: 79–80.
(5) Drain, B. D.
1932. field studies of bud sports in michigan tree fruits. Mich. Agr. Expt. Sta. Tech. Bull. 130, 48 pp., illus.
(6) Kinman, C. F.
1930. a study of some unproductive cherry trees in california. Jour. Agr. Research 41: 327–335, illus.
(7) Morren, C.
1854. le marronier d'inde a fleurs doubles ou le marronier a fleurs de jacinthe. Belg. Hort. 4: 153.
(8) Shamel, A. D., Pomeroy, C. S., and Harmon, F. N.
1931. bud variation in bartlett pear trees. Jour. Heredity 22: 81–89.
(9) ——— Scott, L. B., and Pomeroy, C. S.
1918. citrus-fruit improvement; a study of bud variation in the washington navel orange. U. S. Dept. Agr. Bull. 623, 146 pp., illus.
(10) ——— Scott, L. B., and Pomeroy, C. S.
1918. citrus-fruit improvement; a study of bud variation in the valencia orange. U. S. Dept. Agr. Bull. 624, 120 pp., illus.
(11) ——— Scott, L. B., Pomeroy, C. S., and Dyer, C. L.
1920. citrus-fruit improvement; a study of bud variation in the lisbon lemon. U. S. Dept. Agr. Bull. 815, 70 pp., illus.
(12) Thayer, P.
1922. a variation in the downing gooseberry. Jour. Heredity 13: 284, illus.

U. S. GOVERNMENT PRINTING OFFICE: 1935